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GENERAL ASTRONOMY.

TIDAL THEORY OF THE FORMS OF COMETS.*

GEORGE W. COAKLEY.†

In Fig. I let C be the center of a comet, Donati's for example, when so far from the Sun, at S, on June 2nd, 1858, that it appeared of a spherical form with a diameter of 3′, according to Professor Newcomb's statement, Popular Astronomy, page 380.

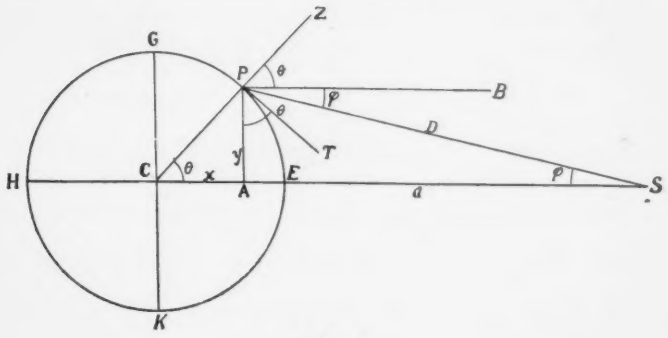

FIG. 1.

Let $CS = a$ = the comet's radius-vector, or distance from the Sun; $CA = x$, $AP = y$, P being any point at the distance $CP = R$ from the comet's center, whether on its surface, or on a concentric circle within it. Let the circle, $EGHK$, represent any section of the comet, in any direction, made by a plane passing through the Sun's center, and that of the comet. Let $PS = D$ = the distance of the particle, P, from the Sun, and let PB be parallel to CS, and PT be a tangent to the circle at P, and considered as having a positive direction when the particle, P, begins to move along it in a right-handed direction counted around the circle, or from P towards E. In the opposite direction, from P towards G, or to

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the left around the circle, it must be counted as negative. PA is drawn perpendicular to CS, and CPZ is the normal to the circle at P.

The accelerative attraction of the Sun on P, if his mass is M, is $\frac{M}{D^2}$, omitting the constant factor k used by Professor Watson. The component of this acceleration, in the direction PB, is $\frac{M}{D^2}\cos\varphi$. The acceleration of the comet as a whole, at C, is $\frac{M}{a^2}$. The disturbing force of the Sun, which tends to draw away the particle, P, from the comet in either of the parallel directions, CS or PB, is the difference of these two accelerations, or

$$\frac{M}{D^2}\cos\varphi - \frac{M}{a^2}.$$

Let this disturbing force be resolved into the two normal and tangential components, acting in the directions PZ and PT respectively. Denoting them by N and T, they will evidently be:

$$N = \left(\frac{M}{D^2}\cos\varphi - \frac{M}{a^2}\right).\cos\vartheta,^*$$ acting along PZ, and

$$T = \left(\frac{M}{D^2}\cos\varphi - \frac{M}{a^2}\right).\sin\vartheta,$$ acting along PT.

There will also be what may be called a Pressure Component of the Sun's acceleration, $\frac{M}{D^2}$, acting along PA, whose value is $\frac{M}{D^2}\sin\varphi$. If this be resolved in the directions PC and PT, and if they are denoted respectively by n and t, since they are in the normal and tangential directions, they will be

$$n = -\frac{M}{D^2}\sin\varphi\sin\vartheta,$$ in the direction PC,

$$t = +\frac{M}{D^2}\sin\varphi\cos\vartheta,$$ in the direction PT.

The negative sign belongs to the first of these because it tends to diminish the radius, R, while the component, N, tends to increase it, and is therefore positive.

The component N, which tends to remove the particle P in the direction PZ is resisted, or restrained, by the gravity of the comet or the attraction of its mass, m, towards C. As this force tends to diminish the radius, R, it must be considered as negative, and

* $\vartheta = \theta$ of Fig. 1.

may be represented by $-\frac{m}{R^2}$. Hence the particle, P, will be kept in equilibrium, so far as the normal forces are concerned, when

$$-\frac{m}{R^2}+n+N=0, \text{ or}$$

$$-\frac{m}{R^2}-\frac{M}{D^2}\sin\varphi\sin\vartheta+\left\{\frac{M}{D^2}\cos\varphi-\frac{M}{a^2}\right\}\cos\vartheta=0.$$

From Fig. I it is evident that $x=R\cos\vartheta$, $y=R\sin\vartheta$, also $a-x=D\cos\varphi$, $y=D\sin\varphi$.

$$\therefore D^2=(a-x)^2+y^2=a^2-2ax+x^2+y^2$$

$$\therefore D^2=a^2-2aR\cos\vartheta+R^2=a^2\left(1-2\frac{R}{a}\cos\vartheta+\frac{R^2}{a^2}\right),$$

Let $\beta=\frac{R}{a}$, $\therefore D^2=a^2(1-2\beta\cos\vartheta+\beta^2)$

$$\therefore D=a(1-2\beta\cos\vartheta+\beta^2)^{\frac{1}{2}}$$

$$\cos\varphi=\frac{a-x}{D}=\frac{a-R\cos\vartheta}{a(1-2\beta\cos\vartheta+\beta^2)^{\frac{1}{2}}}=\frac{1-\beta\cos\vartheta}{(1-2\beta\cos\vartheta+\beta^2)^{\frac{1}{2}}}$$

$$\sin\varphi=\frac{y}{D}=\frac{R\sin\vartheta}{a(1-2\beta\cos\vartheta+\beta^2)^{\frac{1}{2}}}=\frac{\beta\sin\vartheta}{(1-2\beta\cos\vartheta+\beta^2)^{\frac{1}{2}}}$$

$$\frac{M}{D^2}\cos\varphi=\frac{M}{a^2}\cdot\frac{1-\beta\cos\vartheta}{(1-2\beta\cos\vartheta+\beta^2)^{\frac{3}{2}}}$$

$$\frac{M}{D^2}\sin\varphi=\frac{M}{a^2}\cdot\frac{\beta\sin\vartheta}{(1-2\beta\cos\vartheta+\beta^2)^{\frac{3}{2}}}$$

$$\therefore \text{(A)}\quad \begin{cases} N=\dfrac{M}{a^2}\left\{\dfrac{1-\beta\cos\vartheta}{(1-2\beta\cos\vartheta+\beta^2)^{\frac{3}{2}}}-1\right\}\cdot\cos\vartheta, \text{ in direction } PZ. \\ T=\dfrac{M}{a^2}\left\{\dfrac{1-\beta\cos\vartheta}{(1-2\beta\cos\vartheta+\beta^2)^{\frac{3}{2}}}-1\right\}\cdot\sin\vartheta, \text{ in direction } PT. \end{cases}$$

$$\text{(B)}\quad \begin{cases} n=-\dfrac{M}{a^2}\cdot\dfrac{\beta\sin^2\vartheta}{(1-2\beta\cos\vartheta+\beta^2)^{\frac{3}{2}}}, \text{ in the direction } PC. \\ t=+\dfrac{M}{a^2}\cdot\dfrac{\beta\sin\vartheta\cos\vartheta}{(1-2\beta\cos\vartheta+\beta^2)^{\frac{3}{2}}}=\dfrac{M}{2a^2}\cdot\dfrac{\beta\sin 2\vartheta}{(1-2\beta\cos\vartheta+\beta^2)^{\frac{3}{2}}}, \end{cases}$$

in the direction PT.

We shall first discuss the Pressure Components, (B). Of these the normal component, n, is evidently zero, both at E and at H, where $\sin\vartheta=0$; but at G and K, denoting them by n_2 and n_4, they are

$$n_2=n_4=-\frac{M\beta}{a^2}(1+\beta^2)^{-\frac{3}{2}}=-\frac{MR}{a^3}(1-\tfrac{3}{2}\beta^2), \text{ nearly.}$$

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Hence the Sun's normal pressure is greatest at right-angles to the line joining the centers of the Sun and comet, and is directed both at G and K towards the comet's center. This force tends to compress the spherical figure of the comet into an ellipsoid of revolution around the greater axis, which is directed towards the Sun.

The tangential component, t, of the Sun's pressure is evidently zero at each of the points E, G, H, K, where $\sin 2\phi = 0$. But it will have a maximum value at the middle of each of the quadrants EG, GH, HK, KE, where $\sin 2\phi = \pm 1$. Denoting that at the middle of the first quadrant by $t_{\frac{1}{2}}$, it will be

$$t_{\frac{1}{2}} = + \frac{MR}{2a^3} (1 - \beta\sqrt{2} + \beta^2)^{-\frac{3}{2}},$$

$$\text{or nearly } t_{\frac{1}{2}} = + \frac{MR}{2a^3} (1 + \tfrac{3}{2} \beta\sqrt{2}) .$$

It will diminish both towards E and towards G, but will have always the positive sign, and will therefore tend to move the particle, P, along the circle towards the right, or towards E.

The tangential component at the middle of the fourth quadrant, which may be represented by $t_{\frac{7}{2}}$, will be

$$t_{\frac{7}{2}} = - \frac{MR}{2a^3} (1 - \beta\sqrt{2} + \beta^2)^{-\frac{3}{2}} = - \frac{MR}{2a^3} (1 + \tfrac{3}{2}\beta\sqrt{2}), \text{ nearly.}$$

It is negative, as are all the tangential components of the Sun's pressure in this quadrant, and hence they tend to move the particle P in the negative, or left handed direction around the circle, or still towards E.

The tangential component, t, at the middle of the second quadrant, or

$$t_{\frac{3}{2}} = - \frac{MR}{2a^3} (1 + \beta\sqrt{2} + \beta^2)^{-\frac{3}{2}} = - \frac{MR}{2a^3} (1 - \tfrac{3}{2}\beta\sqrt{2}) \text{ nearly.}$$

It is negative like the others in this quadrant, and tends to move P in the left handed direction, or towards H.

In the middle of the third quadrant it is

$$t_{\frac{5}{2}} = + \frac{MR}{2a^3} (1 + \beta\sqrt{2} + \beta^2)^{-\frac{3}{2}} = + \frac{MR}{2a^3} (1 - \tfrac{3}{2}\beta\sqrt{2}) \text{ nearly.}$$

Like the other tangential components of the Sun's pressure in this quadrant, it tends to move P towards the right or back to H.

Hence the tangential components of the Sun's pressure tend always to transfer the comet's materials along the surface, for each

value of R, from the positions G and K towards E, nearest the Sun, and towards H, farthest from him. This process will also tend to increase the diameter HE, and to diminish that, GK, at right-angles to the Sun's direction. But it should also be noticed that the maxima and other values in the two quadrants nearest the Sun have the factor $1 + \frac{3}{2}\beta\sqrt{2}$, while those in the two quadrants, or hemisphere, farthest from the Sun have the factor $1 - \frac{3}{2}\beta\sqrt{2}$. Hence more matter is conveyed by these tangential currents into the hemisphere nearest the Sun, than is conveyed by the feebler currents into the hemisphere farthest from him. The consequence of this is, that the effect of the tangential components of pressure is to *transfer the comet's center of gravity away from its center of figure* TOWARDS THE SUN.

DISCUSSION OF THE NORMAL AND TANGENTIAL COMPONENTS OF THE DISTURBING FORCE, N AND T.

At E, or the beginning of the first quadrant, let these components be denoted respectively by N_1 and T_1.

$$\text{Hence } N_1 = \frac{M}{a^2} \cdot \left\{ \frac{1-\beta}{(1-\beta)^3} - 1 \right\} = \frac{M}{a^2} \left\{ (1-\beta)^{-2} - 1 \right\}$$

$$\therefore N_1 = \frac{M}{a^2} \cdot \left\{ 2\beta + 3\beta^2 + 4\beta^3 + 5\beta^4 + \text{etc.} \right\}$$

$$\therefore N_1 = \frac{M \cdot 2R}{a^3} (1 + \tfrac{3}{2}\beta + \tfrac{4}{2}\beta^2 + \tfrac{5}{2}\beta^3 + \text{etc.})$$

and $T_1 = 0$, since $\sin \vartheta = 0$.

Denoting these components at G, by N_2 and T_2, they will be found to be

$$N_2 = 0, \text{ since } \cos \vartheta = 0,$$

$$T_2 = \frac{M}{a^2} \left\{ (1+\beta^2)^{-\frac{3}{2}} - 1 \right\} = -\tfrac{3}{2}\beta^2 \frac{M}{a^2} \text{ nearly}$$

$$\therefore \quad T_2 = -\tfrac{3}{2} \frac{MR^2}{a^4} \text{ nearly.}$$

Similarly at H and K, will be found for N_3, T_3 and N_4, T_4,

$$N_3 = -\frac{M}{a^2} \left\{ (1+\beta)^{-2} - 1 \right\} = -\frac{M}{a^2} \left\{ -2\beta + 3\beta^2 - 4\beta^3 + 5\beta^4 - \text{etc.} \right\}$$

$$T_3 = 0.$$

$$\therefore \quad N_3 = \frac{M \cdot 2R}{a^3} (1 - \tfrac{3}{2}\beta + \tfrac{4}{2}\beta^2 - \tfrac{5}{2}\beta^3 + \text{etc.})$$

$$N_4 = 0,\ T_4 = -\frac{M}{a^2}\left\{(1+\beta^2)^{-\frac{3}{2}} - 1\right\} = -\frac{M}{a^2}\left\{-\tfrac{3}{2}\beta^2\right\}$$

$$\therefore\ T_4 = +\tfrac{3}{2}\frac{MR^2}{a^4} \text{ nearly.}$$

At E, Fig. I, $T_1 = 0$; at G, $T_2 = -\tfrac{3}{2}\frac{MR^2}{a^4}$ nearly; and it is easy to see that when $\psi > 0$, and $\psi < 90°$, T must be positive up to some point on the quadrant EG, where it must again become zero without $\sin\psi = 0$, after which it will be negative up to and including G. This point on EG will be determined by the condition

$$\frac{1-\beta\cos\psi}{(1-2\beta\cos\psi+\beta^2)^{\frac{3}{2}}} - 1 = 0.$$

An approximate solution of this equation gives

$$\cos\psi = \tfrac{3}{4}\beta, \text{ nearly.}$$

As β is generally small, hence ψ will be large, or the required point not far from G. Hence the tangential component of the disturbing force T_1 in the first quadrant, is positive, or right-handed, up to near G. Like the tangential component of the Sun's pressure, it produces a flow of the comet's fluid material from near G towards E. Similarly the flow takes place from near K towards E; and in the second and third quadrants, the flow of material takes place from near G and K towards H. Hence a further increase of the diameter HE, at the expense of the diameter GK.

In addition to the increase of the diameter HE, and the diminution of the diameter GK, by both the normal and tangential components of the Sun's pressure, and also by the tangential components of the Sun's disturbing force proper, or T, there is an increase of the diameter HE by the normal components, N_1 and N_3 and by similar components, which may be called the Solar Tidal Forces. These forces tend to raise tides of unequal magnitude, in the hemisphere GEK, directly towards the Sun, and in the hemisphere GHK, away from him, that towards the Sun being the greater. The type of the tide raised nearest the Sun may be considered as represented approximately by the disturbing force,

$$N_1 = \frac{M}{a^3} \cdot 2R \cdot \left\{1 + \tfrac{3}{2}\beta + \tfrac{4}{2}\beta^2 + \tfrac{5}{2}\beta^3 + \text{etc.}\right\}. \qquad \text{(I).}$$

That of the tide in the opposite hemisphere, GHK, by the disturbing force,

$$N_3 = \frac{M}{a^3} \cdot 2R \cdot \left\{1 - \tfrac{3}{2}\beta + \tfrac{4}{2}\beta^2 - \tfrac{5}{2}\beta^3 + \text{etc.}\right\}. \qquad \text{(II).}$$

It will be perceived that the maxima disturbing forces, N_1 and N_3, on account of the smallness of β, in general, are nearly in proportion directly to the *mass* of the disturbing body, M, inversely proportional to the *cube* of the disturbed body's distance, a, from the disturbing body, and directly as the diameter, or radius, R, of the disturbed body.

But the effect of these disturbing forces in raising these tides will also depend greatly on the force by which they are resisted, namely the gravitation toward the center of gravity of the disturbed body, principally at its surface, E and H, but more or less also at other distances from the center, C. It will be instructive to compare these forces, and their effects in producing the tides in the waters of the earth, with what they ought to be, when similarly computed, for a given comet, as Donati's.

With the Earth's mean distance from the Sun, considered as constant, its known mass, compared with that of the Sun, $m = \frac{1}{354936}$, according to Professor Watson's tables in his Theoretical Astronomy, that of the Sun being the unit, and its known radius, R, the forces N_1 and N_3, for the Earth's solar tides, are readily computed. But these forces are so resisted by gravity at the Earth's surface, which may be represented by $g = \frac{m}{R^2}$, that the highest tides raised on the Earth, at E and H, by the Sun alone, are about one foot in the open ocean, far away from any land except a small island. According to Professor Newcomb, Donati's comet was first discovered on June 2, 1858, with an apparent diameter of 3′. How large was the comet then, and how far from the Sun was it? From the elements of the comet given by Professor Watson, No. 248 of his Catalogue of Comets, which elements were computed by Professor G. W. Hill, it appears that the comet was then in the part of its orbit 120 days before perihelion passage, which was nearly on Sept. 30. With these data the comet's radius-vector, or distance from the Sun, computed by Watson's formulæ and tables, both as a parabola and as an ellipse, was a little more, especially in the ellipse, than two and a quarter times the Earth's mean distance from the Sun.

Using the solar parallax, 8″.848, and the Earth's equatorial radius given by Professor Chauvenet (Spherical and Practical Astronomy), the Earth's mean distance was found in miles, and thence that of the comet. Then, from the 3′ apparent diameter of the comet, its diameter was found to be, on June 2, 1858, somewhat more than 182,000 miles. Hence the radius of the comet was at least $R = 91{,}000$ miles, or nearly 23 times the

Earth's equatorial radius. Professor Newcomb says, (Popular Astronomy, page 380), "No tail was noticed until the middle of August, and at the end of that month it was only half a degree in length, while the comet itself was barely visible to the naked eye." About the middle of August would bring the comet to within 45 or 46 days of its perihelion passage. At that time, by Watson's formulæ, the comet would be a little more distant from the Sun, than the Earth was. Supposing the comet to have then the same diameter, $HE = 2R = 182{,}000$ miles, or 23 times the Earth's diameter, it is evident from (I) and (II), that the Sun's disturbing forces would tend to raise tides at E and H, 23 times as great as they would on the Earth at the same distance, or nearly 23 feet instead of one foot. But the actual heights of the tides raised by the forces N_1 and N_3 would also depend upon the strength of the forces tending to counteract their effect. On the Earth the counteracting forces are mainly the gravity $g = \frac{m}{R^2}$, acting at E and H toward the centre C. To determine what these counteracting forces are on the comet its mass, m, as well as its radius, R, must be known. La Place's limit of a comet's mass, to produce no perturbation in the solar system, is $\frac{1}{5000}$ of the Earth's mass. It is better perhaps to make the following supposition. Since it is known that the Earth's atmosphere is about $\frac{1}{1000000}$ of the Earth's mass, let it be supposed that the mass of Donati's comet is equal to 400 times that of the Earth's atmosphere. It will then be $m = \frac{400}{1000000} = \frac{1}{2500}$ of the Earth's mass. This is just twice as great as La Place's limit.

As the comet's radius is 23 times that of the Earth, hence the gravity at its surface, at E or H, is $g' = \frac{g}{2500 \times 23^2}$, where g = the gravity at the Earth's surface, and g', that at the comet's. Hence $g' = \frac{g}{1{,}322{,}500}$.

As this restraining force of gravity on the comet's surface is so much smaller than it is on the Earth, the 23 feet elevation of the tides at E and H, in the case of the comet, must be increased 1,322,500 times or 30,417,500 feet, or about 5,760 miles, nearly one-sixteenth the length of its radius.

Without intending this as an absolutely accurate and definite calculation on the subject, in all its complicated details, it is sufficient perhaps to show how enormous the Sun's tidal disturbance of the comet's figure of equilibrium must be, even when it is as far from him as the Earth is, considering how small the

comet's mass is, compared with that of the Earth, and how large its diameter is. But when the comet runs down still nearer to the Sun, it gains nothing, as a whole, in its restraining power over the disturbing forces; but these are again enormously increased inversely proportional to the cube of the comet's distance from the Sun.

The difference between the tidal forces towards the Sun, and on the comet's side turned away from him, being greater in the former case, tends still farther to transfer the comet's centre of gravity towards the Sun, in the same direction namely as its transference by the pressure and tangential components.

That this change of the comet's centre of gravity is not a small one may be understood from the following considerations. When Mr. Croll, the English geologist, first published his views with regard to a large ice-cap placed over one of the Earth's polar regions, the north pole for example, and the removal of all ice from the opposite pole, he computed that there would be, in consequence, a considerable displacement of the Earth's centre of gravity towards the pole on which the ice-cap rested. A scientific friend brought these results to my notice; but I was disposed to doubt, or deny, that the effect of such an ice-cap could change the Earth's centre of gravity by any appreciable amount, because the mass of the supposed ice-cap may be regarded as almost infinitesimal compared with the mass of the Earth.

But, said my friend, try the calculation yourself, and tell me how great is the change of the centre of gravity, for an ice-cap at the north pole, say one mile high, and thinning down to zero thickness at 45° north latitude. On making the calculation, by supposing the mass of the Earth, without the cap, with the mean density of 5.6, to have its centre of gravity, or its weight, at the centre of a sphere with the Earth's mean radius, and computing the weight and position of the ice-cap's centre of gravity, with a mean density of 0.92, the place between these two points,—the earth's center, and the ice-cap's center of gravity,—where the two weights, on opposite sides of a fulcrum, would balance each other, was found, to my surprise, at a large fraction of a mile from the Earth's centre. Then it was easy to see that while the ice-cap was really but a small fraction of the Earth's mass, yet its power of changing the centre of gravity really depended upon the *very great leverage* at which it acted; nearly four thousand miles.

In the same manner, although the mass of the comet that is transferred towards the Sun, in excess of that transferred to the

opposite side, may be comparatively small, yet the enormous leverage at which it acts, in the case of the comet, 23 times as large as the Earth, and only $\frac{1}{2500}$ of the Earth's mass besides, would necessarily change its centre of gravity towards the Sun by a very large amount.

Again Mr. Croll inferred from the displacement of the Earth's centre of gravity towards that of the ice-cap, that the moveable waters of the Earth would be drawn towards the new centre of gravity, arraying themselves somewhat spherically around this new centre, and thus throwing a still larger mass of water upon the hemisphere containing this centre. The effect of this would be to still farther transfer the centre of gravity in the same direction, until a new equilibrium of all the forces could be established.

Exactly in the same way, the transference of the comet's centre of gravity towards the Sun, by the forces previously discussed, would cause an additional portion of its fluid mass to move towards the Sun, especially at the comet's surface, and thus still farther remove its centre of gravity towards the Sun.

The next important consequence, resulting from this change of the comet's centre of gravity, is that the radius, R, in the two formulæ, (I.), (II.) on page 182, or in the expressions for the Sun's normal disturbing forces at E and H of Fig. I, can not be the same. For the R in (I.), counted from the comet's centre of gravity, is now *diminished*, while that of (II.) is *increased*. Let the smaller R, in N_1 be denoted by R_1, the greater in N_3 by R_3. Then the new values of N_1 and N_3 are, denoting them by an accent placed above them,

$$N_1' = \frac{M}{a_3} \cdot 2R_1 \cdot \left\{1 + \frac{3}{2} \cdot \left(\frac{R_1}{a}\right) + \frac{4}{2} \cdot \left(\frac{R_1}{a}\right)^2 + \frac{5}{2} \cdot \left(\frac{R_1}{a}\right)^3 + \&c.\right\}. \quad (I'.)$$

$$N_3' = \frac{M}{a^3} \cdot 2R_3 \cdot \left\{1 - \frac{3}{2} \cdot \left(\frac{R_3}{a}\right) + \frac{4}{2} \cdot \left(\frac{R_3}{a}\right)^2 - \frac{5}{2} \cdot \left(\frac{R_3}{a}\right)^3 + \&c.\right\}. \quad (II'.)$$

At the same time the restraining force of the comet's gravity at its surface, at E and H respectively, will be $g_1' = \frac{m}{R_1^2}$, and $g_3' = \frac{m}{R_3^2}$.

Thus it is evident that the normal disturbing force, N_1' for raising the tide at E, nearest the Sun, is now, in consequence of the displacement of the comet's centre of gravity, less than the opposite normal disturbing force, N_3', at H. At the same time, the comet's restraining force, at E, g_1' is now greater than that, g_3', at H. In other words, the comet, by the change of its centre of

gravity, has *gained control* over its surface *towards the Sun*, and it has *lost control* over that part of its surface turned away from him.

For a distance, R_1, from the new center of gravity, in the direction towards H, away from the Sun, the gravity $g_1' = \frac{m}{R_1^2}$ will be the same as that towards the Sun. Hence the mass of the comet, at the new center of gravity, will tend to collect a spherical portion of its fluid materials around this center, in every direction at the distance R_1; but the more distant portions, out to the limit R_3, will be less attracted, and rarer or less dense, as long as the attraction $\frac{m}{R_3^2}$ is greater than N_3'.

The tendency will evidently be to form a dense nucleus at, and very near the comet's center of gravity, and a less dense spherical *head* or *coma* around the nucleus, or radius R_1. The comet's figure will be more or less that of an elongated ellipsoid, with the longest axis directed towards the Sun, the nucleus and head being nearest to him.

With the decrease of the comet's distance from the Sun, the disturbing forces will increase inversely as the cube of the radius-vector, the two radii, R_1 and R_3, will become more and more unequal, and the control of the comet's attraction on its materials turned away from the Sun, less and less, until finally the Sun's disturbing force in this direction becomes too great for the comet's attraction to control its figure of equilibrium in the direction away from the Sun. The figure will, therefore, be *ruptured*, and the tail of the comet will be formed of a somewhat paraboloidal form, rather than the previous ellipsoid.

The nucleus and head of the comet will now journey down towards the perihelion, with accelerated velocity; the more distant tail following more slowly along nearly the same orbit.

When the nucleus and head of the comet shall have approached very near the perihelion, their velocity will be exceedingly great, since it is nearly inversely as the square-root of the distance from the Sun. But the greater part of the tail will be spread out backwards along the orbit to such great distances, and will be moving so much more slowly in consequence, that the nucleus and head will be forced to break away from all connection with these portions of the tail. The nucleus and head, containing the greater part of the comet's mass, having passed the perihelion, and now receding from the Sun, his action on them will be exactly the same as before they passed the perihelion. That is, he

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will still draw the center of gravity nearest to him, and the action on the more remote parts will as closely *resemble* a repulsive force by which he will *seem* to drive them away from him, as was the case *before perihelion passage*. But, in neither case is there any *real repulsion*; only the same *difference of attraction* by which the tides in the Earth's waters are produced.

The portions of the tail, separated from the head and nucleus at perihelion passage, will subsequently, at their proper times, according to their distance from perihelion, pass around that point, and move in a somewhat wide track along nearly the same orbit, spread over a considerable arc of the orbit. Having reached the perihelion later than the comet's head, they will never be able to overtake it, as both are retarded alike in their journey towards aphelion, if the orbit be a long ellipse. When the head arrives at aphelion it begins to be accelerated again towards perihelion, while the separated portions of the tail are yet climbing with retarded velocity towards the aphelion. Of course their chance of overtaking the head is diminished still more.

At the next and at each return of the comet to perihelion, a like separation takes place, and thus the materials of the comet become gradually strewn around the orbit, in their patches, forming those nebulous bodies that produce the meteor-swarms whenever the orbit of the comet happens to nearly intersect the orbit of the Earth.

This tidal theory of the forms of comets, and of their disruptions without scattering the fragments into outer space, beyond the Solar System, as the repulsion theory requires, is the only one, so far presented, that accounts for the Leonid, the Perseid, and other swarms of shooting stars, with a recognized comet pursuing the same general orbit as the meteoric bodies themselves.

No claim is hereby made to any originality in this tidal theory of comets. For it seems obvious that it ought to present itself naturally to anyone, as it did to me, who should reject, as I always did, the repulsion theory, on account of its inconsistency with the abundantly verified Newtonian Law of Gravity.

On speaking to a mathematical friend, more than thirty years ago, of this tidal theory of comets, he informed me that he had heard that such a theory had been maintained by one of the Professors at Hamilton College, New York. Professor Newcomb mentions that Professor B. Peirce of Harvard maintained that the nucleus of a comet must possess metallic density to prevent its being torn to fragments by the Sun's tidal forces at perihelion.

Somewhere about 1860 or 1861, I found a statement by M. Faye, the discoverer of the comet that bears his name, to the effect that on seeing the great comet of 1843, he said to Arago, "There is a magnificent tide produced by the Sun on the comet." "No," said Arago, "it cannot be a tide, because, if it were, there should be a tail of equal length pointing *towards the Sun*."

Thereupon M. Faye gave up the idea of the tide, and fell back upon the repulsion theory. But Arago was not warranted in pushing so closely the analogy of the *small tides* on so *small a body*, and so *great a mass*, as the Earth, at a great and constant distance moreover from the disturbing body, to the extreme case of the *large bodies, small masses*, and *greatly varying distances* of the comets from the Sun.

OBSERVATIONS OF JUPITER MADE WITH THE 16-INCH EQUATORIAL OF GOODSELL OBSERVATORY.*

H. C. WILSON.

During the fall and winter of 1891, I have observed the planet Jupiter on quite a number of nights, with the 16-inch equatorial of Goodsell Observatory. On several nights sketches were made of the detail which could be seen. Four of these sketches are given with this paper (Plate VII.). As some of the notes made may be of interest to amateur astronomers, I give the substance of them here.

Aug. 31, 1891, $12^h\ 30^m$ central time.—A sketch (No. 1) shows eight belts, one of them exceedingly narrow and lying almost exactly on the planet's equator. On the northern edge of the first northern belt near the meridian are two small dark spots with a white spot between them. On the southern edge of the next northern belt are two more small dark spots. All of these dark spots are slightly elongated parallel to the equator.

Sept. 3, $12^h\ 10^m$, $12^h\ 20^m$ central time.—Sketch (No. 2) shows eight belts, one very narrow one lying close to the planet's equator. The great red spot has its preceding end on the meridian. Just south of this on the meridian is a small white spot. Another white spot is on the same parallel nearly half way to the preceding limb of the planet. Beyond this the belt in which the white spots lie is very dark. The belt where it passes the great red spot seems to be pushed aside, not resuming its orginal

* Communicated by the author.

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latitude until it is some distance past the spot. There are three small dark spots in the second northern belt and two in the third northern belt. All five are past the meridian.

Sept. 25, 11^h central time.—Partial sketch shows the great red spot on the meridian. The spot encroaches upon the belt just south, apparently pushing it aside and making it denser, as a stream of water is made deeper by being forced through a narrow channel. Five small white spots are seen in this belt, one in conjunction with the preceding end of the great red spot, another near the following end of the red spot. The great southern belt is very much darkened in the portion opposite the preceding end of the great red spot. There are two small dark spots in the north edge of the first northern belt near the following limb of the planet. The center of the great red spot was not quite up to the central meridian at 10:50; on meridian at 10:54; certainly past meridian at 10:58 central time.

Oct. 8.—Long red spot in second southern belt had its center on the central meridian of Jupiter at $10^h\ 12^m \pm 2^m$ central time. This spot is very prominent, bright crimson in color, almost a parallelogram in shape.

Oct. 15, $8^h\ 30^m$.—A white spot south following the great red spot was on meridian at $8^h\ 30^m$. The sketch (No. 3) shows the great red spot half way from the meridian to the left limb of the planet. The central portions are covered with a white cloud. The great southern belt is very intense especially near the great spot, and is curiously narrowed, like a pencil point, toward the left. On the northern edge of this belt about half way from the center to the east limb is a curious projection curved to the left with a white indentation preceding it. The second southern belt is strangely curved to the south connecting with the next belt. The narrow belt on the equator is distinctly shown.

Oct. 27.—A round white spot preceded by a very dark shading, on the lower edge of the great southern belt, was at the central meridian at $8^h\ 20^m$. Great red spot a little more than half way from meridian to left edge of disk.

Oct. 30.—Shadow of Satellite III was noticed beginning transit at $6^h\ 18^m$. Satellite I reappearing from eclipse was first noticed at $7^h\ 08^m\ 35^s$; very faint; it had regained its normal brightness at $7^h\ 11^m\ 35^s$.

Nov. 9.—While showing Jupiter to visitors I noticed the three satellites (I, III and IV) in the form of a small triangle to the left of (preceding) the planet. The upper one of the three is much fainter and bluer in color than the other two. [The upper

one was IV. The transit of its shadow had occurred two or three hours earlier. A rough sketch indicates that III was about twice as bright as I and the latter twice as bright as IV].

Nov. 16, 7^h central time.—Satellite IV is much fainter than any of the others and of a darker color. Air hazy. [IV was on left side of planet. Occultation occurred 13 hours later].

Nov. 17, 7^h-8^h.—Satellite III reappeared from eclipse just above (south of) IV, while I was examining the latter. I first noticed it at $7^h\ 28^m\ 50^s$, when the appearance of the two satellites was that of a very unequal double star. At $7^h\ 29^m\ 40^s$, the two were equal in brightness and a minute later III was at least twice as bright as IV. III was perceptibly elongated while coming out of eclipse, but round afterward. [IV was then on the right side of the planet, about to be eclipsed an hour later. No note is made of color and, as I now recollect, it did not differ much from that of the other satellites].

Nov. 19.—The long red patch in the second belt south of Jupiter's equator was on the central meridian at $8^h\ 18^m$.

Nov. 23.—Sky hazy and image fuzzy except at moments. I was surprised, as I have been several times lately, by the faintness and bluish color of satellite IV. This satellite was on the left of the planet, about ⅔ diameter distant, and approaching. The satellites on the left of the planet form a descending series as to their apparent diameters. The one farthest out has double the diameter of the next and that double the diameter of the one nearest the planet. These are not the real disks of the satellites but are enlarged by poor definition. [I find on comparison with the American Ephemeris that the satellite supposed to be IV in the above observation was really II. IV was on the right of the planet and according to the sketch was about equal to I in brightness. The satellites on the left were in order III, I, II.]

Dec. 12, 7^h.—While showing Jupiter to visitors I was surprised by the faintness and purple color of satellite IV, which had only a couple hours before passed off from the face of the planet. The contrast between its light and that of III, which was very near it, was very striking. IV was very much fainter than I and II.

Dec. 17, $4^h\ 30^m$.—Sketch (No. 4) shows great red spot east of central meridian. White spot exactly over its center surrounded by dark shading. Both spots on meridian at $4^h\ 44^m$. The great southern belt seems narrower than usual and on its northern edge is a series of five projections all curving backward toward the east limb. The white equatorial belt is far from white, being filled with dusky details which are seen indistinctly and cannot be sketched. The narrow dark belt on the equator is not seen.

XUM

Dec. 18, 7^h.—The three visible satellites (IV, I and III) all had a a reddish yellow tint, darker than the planet, which was very white between the dark belts. Definition poor.

Jan. 2, 1892, 5^h and 7^h 30^m.—The satellites were all of the same color, yellowish white, and nearly the same brightness. The three on the right, III, I and II, were almost exactly equal in brightness and color. Magnifying power 200 and 300.

Jan. 4, 5^h 45^m.—Definition fair. White spot on central meridian in middle of first dark belt south of equator. A small dark spot immediately follows and another precedes it by one-fifth diameter of Jupiter's disk on the same parallel of latitude. The satellites are all of nearly the same color, yellowish white, but differ greatly in brightness. In order of brightness they are IV, I, II, III.

Jan. 23, 4^h 30^m.—Satellites of Jupiter were all of the same color, yellowish white. Satellite IV was the faintest and possibly a little darker in color than the others. This satellite was on the right side of the planet, having just reappeared from eclipse.

On every occasion when the great red spot was seen it was conspicuous, having a light red or pink color, quite different from that of the belts on either side. It gave me the impression always of being at a higher level than the other dark markings. The permanence of outline of this spot and of the great belt on its north and the clear white channel between them would suggest a surface of a comparatively solid nature rather than that of cloud formation. Yet a comparison of the drawings accompanying this paper will reveal many marked changes in other portions of the planet's surface.

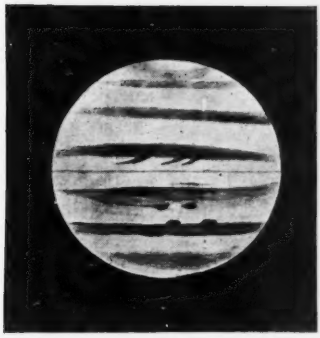
It has been a disputed question whether the portions of the belt next south of the great red spot, which have the same latitude and a shorter period of rotation than the latter, passed over or around it. It has seemed to me at each observation that the dark belt on coming up to the spot was forced aside, there being nearly always a very narrow line of white between the belt and spot. Only on one occasion did the belt seem to encroach upon the spot and that was when the seeing was poor.

The few notes which I have upon the brightness of the satellites go to confirm the view which has been expressed by several, that the variations of brightness always occur in the same parts of the orbits about Jupiter. In each case when IV was noted as especially faint, it was but a short distance to the left (west) of the planet having just passed off from the planet's disk.

I have not, in any case, been able to see any markings upon the

PLATE VII.

1.



Aug. 31, 1891, $12^h\ 30^m$.

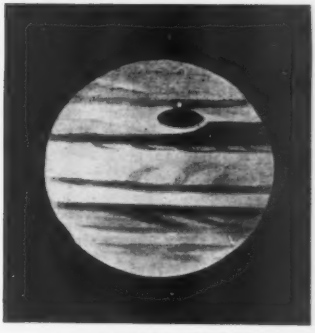
2.

Sept. 3, 1891, $12^h\ 15^m$.

3.

Oct. 15, 1891, $8^h\ 30^m$.

4.



Dec. 17, 1891, $4^h\ 30^m$.

Sketches of Jupiter made with the 16-inch equatorial of Goodsell Observatory by H. C. Wilson.

ASTRONOMY AND ASTRO-PHYSICS,
Vol. XI, No. 103, March, 1892.

satellites. In the best seeing, the disks have always seemed perfectly round except in one instance when satellite III was plainly elongated, the position angle of the elongation being about 30° less than that of the belts of the planet. The satellite was on the preceding side of the planet about to disappear by occultation. Unfortunately no memorandum was made at the time of this observation so that I cannot now tell the date.

THE OBSERVATION OF SPOTS AND MARKINGS OF THE PLANET JUPITER,*

G. W. HOUGH.†

In the publications of the Astronomical Society of the Pacific, No. 5, and more recently in the *Monthly Notices* of the Royal Astronomical Society, November, 1891, Professor Barnard of the Lick Observatory, has called attention to a statement I made some years ago in relation to the value of micrometer measments for fixing the longitude of spots on the planet Jupiter.

Professor Barnard from eleven observations of the Great Red Spot, made at Lick Observatory in 1891, with a 12-inch object-glass, as well as from observations made at Nashville in 1880-82 with a 5-inch object-glass, has attempted to prove that eye-estimates are as exact as micrometer measurements, for determining the time of passage of the Red Spot over the central meridian of Jupiter.

From what has already been published by others, regarding the various sources of error incident to the method of eye-estimates, I imagined that the subject was no longer open for serious discussion.

It seems to me that an eye estimate for longitude on Jupiter, in point of accuracy, holds about the same relation to micrometer work, as the estimation of the position angle and distance of the components of a double star does, to direct micrometrical measurement.

In the *Monthly Notices* of the Royal Astronomical Society for May, 1880, Professor Marth, who for so many years has given us his invaluable ephemerides, has compared with an ephemeris the observations made by thirteen different observers, on the Great Red Spot in 1879.

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* Communicated by the author.

† Director of Dearborn Observatory, Northwestern University.

He says: "The discrepancies between the observations of different observers and on different days point to the existence of some grave source of error."

A comparison of these observations shows that on some days, the observers differed as much as eleven minutes in the time of passage of the center of the Red Spot over the central meridian.

The average "mean" error may be placed at about $\pm$ 2.5^m.

The observations also indicate a personal equation, for each observer; the constant difference between two well-known astronomers amounting to 6.5^m.

In the *Astronomische Nachrichten*, No, 2342, Dr. Schmidt, of Athens, from the reduction of 180 observations, found a "mean" error of $\pm$ 2.57^m for the time of passage of the center of the Red Spot over the central meridian. For good definition he gives the average error $\pm$2^m and for poor definition $\pm$5^m.

In the *Astr. Nach.* No. 2410, Dr. Schmidt has determined the personal equation error for a large number of observers. As compared with his own observations, the personal equation of different observers varies between + 3.6^m and — 5.8^m.

He also found a systematic error depending on the hour-angle of the planet, due to the position of the equator of the planet to the line of sight. The maximum correction for this error was 7^m.

With these facts before us, regarding the gross possible errors incident to the method of eye estimates, it seems to me rather late to claim for it any great degree of precision.

Professor Barnard's excellent observations of the passage of the Red Spot over the central meridian in 1891, are certainly as good as the best micrometer work, but I think these particular observations should be regarded as a happy accident rather than a demonstration of the value of the method of observation.

Professor Barnard is a very careful observer, and the Nashville observations are excellent for the size of the instrument used, but when he claims a "mean" error of $\pm$ 0.7^m for observations made with a 5-inch object-glass and a power 137, I think he has been too hasty in his conclusions.

He says: "In twenty-three of these transits *three* estimates were made of each phase (the ends and middle of the spot) from these I get for the transit of the middle of the mean of the *nine* observations, the error of the transit = $\pm$ 0.7^m."

I do not quite understand what he means by "three estimates of each phase." There is only *one* instant for the time of transit and assuming a great number of different times certainly will not improve its value. A comparison of the observations made dur-

ing any opposition with an ephemeris which will best satisfy them all will indicate the average accidental error on each day, but may not show the personal equation or other constant errors.

In order to get a "mean" error of $\pm 0.7^m$ on the time of transit of the Red Spot over the central meridian, one must be able to bisect the disk of the planet as well as the Red Spot, each within 0″.10 of arc at mean distance; and this degree of accuracy must be accomplished by a single estimation.

The error in astronomical observations of all kinds greatly exceeds this limit. The method of transits, owing to the apparent slow motion of the spots and the absence of a visible meridian, is not susceptible of great precision. A very good illustration of the conditions involved is to imagine a clock dial without any minute hand and all the divisions erased except III and IX. Under these circumstances the problem is to determine when the hour hand is midway between III and IX, or when it is 12 o'clock.

It appears probable that the determination of noon from a clock dial arranged in this way would be affected by all the various sources of error found by Dr. Schmidt for Jupiter observations. On the other hand if one should make repeated measurements of the position of the hand with reference to III and IX, the time of noon could be ascertained with any required degree of precision.

The micrometer method offers the following advantages in the determination of longitudes on Jupiter:

1st. A great saving of time.

2d. The measures are referred to a visible meridian, viz.: the limbs of the planet.

3rd. The ability to make numerous repetitions of the same quantity.

The longitude of a spot, or the time of passage over the central meridian of the disk, can be determined with the micrometer at any distance from the central meridian, provided it is wholly on the disk. I have occasionally observed spots at $1^h\ 20^m$ before or after their passage over the central meridian. Owing, however, to greater difficulty in seeing objects so far from the center of the disk as well as to possible errors in the adopted constants for reduction, viz.: size of the disk, length and latitude of the object observed, such measures are liable to greater error than when made nearer the central meridian.

XUM

The following example of the observations of the Great Red Spot on Nov. 1st, 1880, will illustrate the micrometer method:

Two sets of measures were made when the spot was on the following side, one set near the middle of the disk, and two more sets when on the preceding side.

t = mean of the times when the measures were made.
m = distance from the central meridian, reduced to mean distance.
Δt = reduction in time.
T = time of transit over the central meridian.

t	m	Δt	T	*Diff.*
h m	″	m	h m	m
8 23.6	+ 3.99	+ 22.5	8 46.1	+ 0.8
28.8	+ 2.99	+ 16.8	45.6	+ 0.3
42.1	+ 0.28	+ 1.5	43.6	− 1.7
9 19.8	− 5.89	− 33.6	45.2	− 0.1
23.7	− 6.59	− 37.8	45.9	+ 0.6
		Mean,	8 45.3	± 0.7

In 1880–82 I made a number of sets of measures on each night to ascertain what degree of precision could be reached, but usually the observation consists of a single set of three or four bisections for each limb. The latitudes are determined in precisely the same way.

To sum up the whole matter, it seems to be proved from the observations which have been made by well-known astronomers, as well as from the theoretical consideration of the problem, based on our knowledge regarding astronomical observations in general, that the method of transits for ascertaining the time of passage of the Red Spot over the central meridian of Jupiter is necessarily subject to a mean error of at least $\pm 2.5^{m}$, and a possible error three or four times as great. Aside from the accidental error the personal equation of an observer may amount to a number of minutes.

From what I have said on this subject it is not to be inferred that I consider eye estimates of no value. All observations of planetary phenomena are valuable and during the past twelve years many important contributions in regard to physical phenomena on Jupiter have been made by amateurs and others.

I wish, however, to state emphatically that when it is necessary to get precise measures either of longitude, latitude or magnitude of objects on the disk of Jupiter, the micrometer is vastly superior to any system of estimation.

DISCOVERY OF NEBULÆ.*

LEWIS SWIFT.†

The success of the past year in the discovery of nebulæ has not equalled that of the few years previous, or since the assumption of the directorship of the Warner Observatory, for two reasons, viz.: first, from the presence of haze, clouds, and moonlight, the season has been exceptionally unfavorable; and second, from the sky illumination from the increased number of electric street lights now in nearly every part of the city. And as this method of street lighting has come to stay, at least until some indiscreet individual shall invent one still more damaging to delicate astronomical observation, I thought that perhaps some time might elapse ere my tenth catalogue of 100 nebulæ could be attained, so I have just sent to the *Astronomische Nachrichten* a list of 60 nebulæ discovered since the publication of my ninth regular catalogue, a little more than one and a half years ago.

So detrimental has this sky illumination become that I am seriously questioning whether I shall not be obliged to altogether abandon the search for nebulæ and take up some other branch of work. Though, like the stars, the nebulæ are, doubtless, endless in number, yet there is probably not a single undiscovered bright one in the heavens, so thoroughly has the sky been searched by such persistent gleaners as Sirs William and John Herschel, D'Arrest, Lord Rosse, Stephan, Marsh, Tempel, Stone, Messier and many others. The entire sky does not, probably, hold a dozen so bright as Herschel's Class II, and very few as bright as his Class III yet remain undiscovered between the pole and 25° south of the equator. A very large proportion of the nebulæ in my several lists are very much fainter than the faintest of Sir Wm. Herschel's Class III, his faintest.

To prosper in their finding henceforth the observer must be the possessor of a large telescope with a suitable eye-piece made especially for this work, which quest he should be enthusiastically in love with, and he must have a keenness of vision not vouchsafed to everyone, which he has still farther improved and intensified by long practice in observing what Sir John Herschel declared to be so faint as to be almost spiritual.

I have been led to these remarks by an exceeding effort of vision of a few nights since in endeavoring to re-find a nebula discovered on Dec. 23, 1889, but which I could not subsequently re-

* Contributed by the author.

† Director of Warner Observatory, Rochester, N. Y.

cover, and, therefore, concluded it must have been a comet. It is No. 13 of my ninth catalogue where it stands described as "Exceedingly, exceedingly faint, pretty large, round, first of three. In line with N. G. C. 1417-18. Cometary. Unable to re-find it. Seeing good. Failed also at Harvard College Observatory."

In *Monthly Notices* of December, 1891, Dr. Dreyer, Compiler of the N. G. C. and Director of Armagh Observatory, Ireland, says he several times at Lord Rosse's Observatory saw all three of these nebulæ, and, again, on several occasions could not find them though looked for. Connecting his own observations with those of Sir John Herschel's and with mine, and with D'Arrest's failure to find it, he suggests that it is, possibly, a variable. Fortified with these facts, I, on Jan. 31st ult., essayed to find the missing nebula. The two with which it was in line, were easily seen, but not even a glimpse of the other, using a power of 132. Changing the eye-piece to one giving a power of 195, I, after a prolonged endeavor, gained two glimpses of the object but they almost instantly vanished.

The suspect was not exactly in line with the other two but a little north, agreeing with Sir John Herschel's observation. Sir William Herschel never saw this nebula, as has long been supposed.

I have given some thought to the unraveling of the mystery hanging over this object, and the following solution is satisfactory to myself, at least; viz.: that its first discovery was by Sir John Herschel, who recorded it as No. 305 of his own Catalogue, erroneously considering it as identical with Sir William's III 569 (New General Catalogue, 1397). In trying to reconcile this discrepancy, D'Arrest was unable to find it. Subsequently, it was seen, on several occasions, as I have said, by Dr. Dreyer, but was not again found until picked up by myself as above stated. Sir John Herschel does not describe it; he only says, "First of three; one observation."

If it be not variable, which I can hardly believe it to be, it seems strange that, on one occasion, I should have so easily observed it in sweeping, while, ever afterward, I have not been able to find it even with the most persistent effort, and, with the knowledge of its exact position relative to the other two in the same field. That Dr. Dreyer, too, failed, on several occasions, to find it while well knowing its place, seems unaccountable, if it maintain a uniform degree of brightness.

WARNER OBSERVATORY,
Rochester, N. Y., Feb. 11, 1892.

ASTRO-PHYSICS.

THE OBJECTIVE PRISM.*

Two methods have been used for photographing the spectra of the stars. The first of these methods, placing a large prism over the objective of a telescope, was that employed by Fraunhofer in observing stellar spectra visually. It was also used by Secchi for the same purpose. The second method consists in receiving on the slit of a spectroscope the image of a star formed at the focus of a telescope. This method was used by Dr. Draper and Dr. Huggins, and is that now employed at the Potsdam Observatory. The first of these methods has been used at the Harvard College Observatory during the last seven years. It possesses the advantages that the loss of light is very small, the spectra of all stars contained in the field of the instrument are photographed and slight errors in the clock driving the telescope are unimportant. In fact the clock is made to run a little faster or slower than sidereal time, since otherwise the image of each star would be spread into a narrow line in which the spectral lines could not readily be distinguished. By the change in rate this line moves over the plate at right angles to its length, forming a band whose width depends on the rate of the clock and the duration of the exposure. If the deviation from sidereal time is small, the image moves slowly over the plate, and a photograph will be obtained even if the star is very faint. In this case a long exposure should be used, otherwise the band will be too narrow. A variation in the rate of the clock, or other change affecting the right ascension, will only alter the density and breadth of the spectra. A variation in the differential refraction or other change affecting the declination will alter the direction of the spectral lines, rendering them oblique or curved instead of perpendicular to the direction of the spectrum. This will not affect the intensity of the image. With a slit spectroscope, the image of the star must be kept exactly on the slit, the least deviation causing all the light to be lost. It has, however, the great advantage that a comparison spectrum may be photographed by the side of the stellar spectrum, and the true wave-lengths thus determined directly. This advantage is, however, apparent rather than real, since the hydrogen and other solar lines are present in nearly all the stars, and the wave-lengths of any additional lines may be determined

* Communicated by Professor Edward C. Pickering.

differentially from them. When, however, we wish to obtain the absolute wave-lengths of these lines in order to measure the approach or recession of the stars, the slit spectroscope has hitherto alone been used. This seems to be the only portion of this work for which the objective prism cannot be employed. Experiments are still in progress (see H. C. O. Annals, Vol. XXVI, Part I, page xx,) by which it is hoped this difficulty may be overcome. The success of these experiments would permit a fixed reference line to be photographed upon the spectrum always having the same position with regard to it. The precision with which measures of the spectral lines can be made is sufficient to determine the approach or recession with great accuracy, if only the reference line can be measured equally well. If this can be done the slit spectroscope will possess but few advantages over the objective prism. By the latter method equally good definition may be obtained, since, as the loss of light is smaller, greater dispersion may be used. With the brightest stars, however, it is difficult to obtain a dispersion sufficient to utilize the full advantages of this method. With a large telescope the prism would, of course, be heavy, expensive, and from its thickness, would cause considerable loss of light. The objective prism has special advantages in studying the spectra of the fainter stars, since all in the field of the telescope may be photographed simultaneously. If a photographic doublet is used for an objective all stars of sufficient brightness in a region ten degrees square may be photographed at once. In some cases several hundred spectra appear upon a single 8×10 plate.

With means furnished by Mrs. Draper the spectra of the stars have been photographed at the Harvard College Observatory as a memorial to her husband, the late Dr. Henry Draper. For the brighter stars a telescope having an aperture of eleven inches, and corrected for the photographic rays, has been employed. Four large prisms were placed over the objective and gave spectra about six inches in length. By staining the plate with erythrosin, the sodium line D was photographed in the brighter stars, both components being readily shown.

For the fainter stars one or two prisms only were employed. When the prisms were first attached to the end of the telescope, as their entire weight was about one hundred pounds, heavy weights were fastened to the other end of the tube of the telescope, and also to the end of the declination axis. It was, consequently, a laborious and perhaps dangerous operation to remove and replace the prisms. Therefore spectra and chart

PLATE VIII.

Objective Prism at the Harvard College Observatory.

photographs could not readily be taken on the same night. A great improvement on this process was to remount the prisms in square boxes, which could be slid, like the drawers in a bureau, into a large box permanently attached to the cell of the objective. A series of cast iron rings could be bolted to the tube of the telescope, the weight of each ring being such that it would compensate for the weight of the corresponding prism. As each prism was removed a ring was attached, and it thus became unnecessary to change the counterpoise at the further end of the telescope and declination axis. It was still difficult for one person to make the change and much time was lost if frequent changes were required. The method now employed of attaching the large prisms to the telescope is shown in the accompanying engraving (Plate VIII). Two of the prisms only are now used and they are mounted in a square brass box. This is attached to the end of the telescope by a form of link motion. A cast iron bar is fastened to a pivot on each side of the cell, the line connecting the pivots passing through the centre of gravity of the prisms and box. The bars are also free to turn around pivots attached near the end of the tube of the telescope. At the further end of each bar is placed a counterpoise exactly balancing the prism and box, so that the latter will remain in equilibrium in any position. Two links, one on each side of the square box, connect its end with pivots attached to the tube of the telescope. The dimensions are such that in one position the box containing the prisms lies flat against the end of the cell and in another against the side of the tube. The first of these positions is shown in the photograph. Accidental movements of the prism are prevented by small pins attached to the bars by chains. The prisms can thus be removed and replaced in a few seconds without disturbing the balance of the telescope. About 4,400 photographs have been obtained with this instrument since January, 1886. They include the spectra of all stars north of $-30°$ and sufficiently bright to be photographed in this way. Among other interesting results this has led to the discovery that ζ Ursæ Majoris, β Aurigæ, and probably β Lyræ are close binaries. An expedition has been sent to Peru and similar photographs of the southern stars are now being taken with a telescope having an aperture of thirteen inches.

In a second investigation the Bache telescope is used, which has a photographic doublet for an objective having an aperture of eight inches. The advantages of this form of instrument for photographing very faint celestial objects were first recognized

by the writer in 1869, when preparing to observe the total eclipse of the Sun of that year in Mt. Pleasant, Iowa. As the usual methods were inadequate to photograph the faint exterior portions of the solar corona, a local photographer, Mr. Hoover, was requested to take a photograph with a large portrait lens. The result was very satisfactory (Journal Franklin Institute, Vol. LXII, p. 54) and apparently gave the best picture of the outer corona obtained up to that time. The advantages of the doublet are first the large angular aperture which permits very faint stars to be photographed, and secondly, the extent of the field by which the stars in a large part of the sky can be taken upon a single plate. Good definition is obtained over a region five degrees square, while over a region ten degrees square the definition is sufficiently good for many purposes, such as the classification of spectra, variability in light, etc.

A prism having a refracting angle of thirteen degrees was placed over the objective of the Bache telescope and the entire sky north of — 20° was photographed with this apparatus using exposures of about ten minutes. About twenty-seven thousand spectra of more than ten thousand stars were obtained and are published under the name of The Draper Catalogue (H. C. O. Annals, Vol. XXVI, Part 1, and Vol. XXVII). Similar photographs, with exposures of sixty minutes, cover nearly all the northern sky and serve to classify the spectra of the fainter stars. By using a prism of five degrees, of which the dispersion is less, the spectra of still fainter stars are photographed. This dispersion is sufficient to show any marked peculiarities. Since July, 1885, 3,300 plates were obtained with this instrument at Cambridge and in California. It was sent to Peru in the spring of 1889 where it is now in use, and over 3,200 photographs taken there have already been received. When this instrument was removed from Cambridge, the want of it was so great that Mrs. Draper had another instrument constructed to replace it. This is known as the 8-inch Draper telescope, and with it over 5,300 photographs have been taken since August, 1889.

It is expected that a still further advance will be made with the great photographic telescope, the gift of Miss C. W. Bruce. This instrument will be three times the size of the Bache telescope which it will resemble in form. Its aperture will be twenty-four inches and it should, therefore, photograph stars one or two magnitudes fainter than those obtained with the Bache telescope. It is hoped that with the Bruce telescope satisfactory photographs of the spectra of stars of the tenth and eleventh magnitude may

be obtained. The four glass disks required for the lenses have been cast and are now ready for grinding. The prism, which has an aperture of twenty-four inches, is completed.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., Jan. 23, 1892.

ON THE SPECTROGRAPHIC METHOD OF DETERMINING THE VELOCITY OF STARS IN THE LINE OF SIGHT.*

PROFESSOR H. C. VOGEL.

The experiments made at Potsdam in 1887 showed that, as a result of the extremely sensitive photographic methods employed, a sufficiently great dispersion could be made use of to readily detect and measure the displacement of the spectral lines produced by the motion of the stars in the line of sight. It very soon became clear that the measurement of the stellar spectra admitted of a far greater exactness than the direct observations, and that the disturbances of the atmosphere—the chief cause of the difficulties of the direct method—exert their influence in a lesser degree on the photograph. The very numerous measurements on more than two hundred negatives of forty-seven stars, which are now available, have confirmed this result, and show further that the exactness of the measurements far surpasses the expectations based on the first plates taken with a provisional apparatus, and that the definitive observations have reached a degree of accuracy which in some cases is surprising.

This great accuracy has been secured by an advantageous construction of the apparatus, by its very exact adjustment, and especially by the peculiar methods adopted in measuring the photographs. I have already published several communications on this spectrographic method, viz. one in *Astr. Nach.* No. 2896, a further one announcing the discovery of the motion of α Virginis (*Astr. Nach.* No. 2995), and more recently an article on the employment of iron as a comparison spectrum in spectrographic researches (*Sitzungsberichte der Akademie zu Berlin*, June 4, 1891).†

The reductions of the observations and measurements are at present nearly completed, but the passing through the press will still require several months, and therefore I now take the liberty of presenting a short review of the investigation and its chief

* *Monthly Notices*, Dec. 1891.
† ASTRONOMY AND ASTRO-PHYSICS, Feb. 1892.

results, in the hope that this summary, and more especially the explanation of the method of measuring the plates, may be of value and interest to many who are employed in similar lines of work.

In the construction of the apparatus the following points were taken into consideration: great stability for the smallest possible weight; suitable dimensions of prisms, collimator, and camera objectives, in order to preserve sufficient brightness with the greatest possible dispersion; accurate adjustment of the photographic plate in the focal plane of the camera objective; and exact keeping of the star on the slit of the spectrograph. I have endeavored to satisfy the first two conditions by having the frame made of cast steel, and by giving it a form which offered the greatest possible resistance to flexure. The most suitable dimensions for collimator and camera objective, for the 12-inch refractor to which the spectrograph was to be applied, were found to be 408^{mm} focal length for 34^{mm} aperture.

The two Rutherfurd compound prisms have the following dimensions: Height (length of the refracting edge) 35^{mm}; breadth (perpendicular distance from the refracting edge of the flint-glass prism) 45^{mm}. They are of the most colorless glass obtainable, and the dispersion from F to H amounts for each to about 5°. The camera is constructed of sheet steel; the plate-holders are of brass and can be rigidly connected with the camera. The adjustment of the photographic film in the focal plane of the camera objective is accomplished by a motion of the latter, and can be effected with an accuracy of a fraction of a millimetre. In order to facilitate keeping the image of the star exactly on the slit, a small telescope is so connected with the apparatus that it receives the light which is reflected from the front side of the first prism.

The slit, illuminated by the Geissler tube, which furnishes the comparison spectrum, appears in this telescope as a narrow line of light with the star in the middle, and may be readily so held by means of the slow motions of the refractor. A cylindrical lens is not employed, since, with the slit set parallel to the line of the diurnal motion, a slight widening of the linear stellar spectrum can be readily effected by changing the rate of the driving clock. A very important point in the adjustment of this apparatus is that the optical axis of the collimator shall fall in the prolongation of that of the refractor; this is easily and accurately effected by three screws.

By means of a table giving the proper setting for various de-

grees of temperature the plane of the slit is, before each observation, adjusted to lie in the focus for the rays of the wave-length of $H\gamma$, for which the prisms are set at the angle of minimum deviation, and which appear on the middle of the negative. It is of great importance that the latter be precisely adjusted in the focus of the camera objective. This is likewise effected before each observation according to a table with the argument of the thermometer attached to the instrument. This table has been determined by many experiments, as well as by artificial warming of the apparatus. A false adjustment, which exerts a great influence on the sharpness of the images, and hence on the subsequent measurements, can be at once detected by the lack of distinctness of the image of the artifical hydrogen line, and, similarly, changes of the apparatus which occur during the exposure reveal themselves in the altered appearance of the comparison line.

In nearly all the observations hydrogen has been chosen for the comparison spectrum. The Geissler tube was placed directly in the cone of rays of the refractor, at a distance of 40cm. from the slit, and was set at right angles to the optical axis of the refractor as well as to the slit, aud therefore its light is to be regarded as dispersed on reaching the slit. The tubes used were very thin, so that only a comparatively small amount of light (17 per cent) was lost in passing through them.

A further advantage of this arrangement of the Geissler tube lies in the fact that an exact adjustment of its position is not necessary, and any slight changes in its place during the exposure, due to an altered position of the instrument, can exert no injurious influence; for one can readily see that with an adjustment even several degrees false, the slit would still appear fully illuminated.

At first the time of exposure was regulated according to the brightness of the star and to the chosen width of slit, but later it appeared advantageous to leave the width unchanged at 0.02^{mm} and to give a uniform exposure of one hour. The observer then, however, varied the width of the spectrum to correspond with the brightness of the star. The performance of the apparatus has been tested on the Sun by direct observations and by photographs. In the vicinity of $H\gamma$, where the spectrum is sharpest, nearly all the lines are visible which are contained in Rowland's large photograph of the solar spectrum, in spite of the comparatively small dimensions of the apparatus. Of course very close double lines cannot be separated if the width of the

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slit be greater than that corresponding to the distance between the lines.

One perceives less detail on the photograph than by direct observation, since, on account of the extraordinary delicacy of the lines, some details are lost through the coarseness of the silver grains. The excellent prisms would admit of a much greater magnification of the spectrum by the use of a camera objective of longer focus, and thus make possible the production of still sharper photographs, if the light power of the refractor were not too small and the observations therefore necessarily limited to the brightest stars. I have given in *Astr. Nach.*, No. 2896, a collection of about fifty lines on one of the solar negatives which lie between 431.4 and 436.8$\mu\mu$, and may remark further that my assistant, Dr. Scheiner, has been able to measure 290 lines in the spectrum of α Aurigæ between 412.4 and 466.8$\mu\mu$.

In order to decide further as to the correct adjustment of the apparatus, numerous photographs of the Moon's spectrum, with that of hydrogen for comparison, have been made, and show an absolute coincidence of the corresponding lines. Two photographs of Venus are not without interest as showing the accuracy of the measures as well as the correctness of the adjustment:

	Observed Velocity.	Calculated Velocity.
1889 Jan. 2	−7.8	−7.4 English miles.
Feb. 10	−7.4	−7.8

The measurement of the spectra is accomplished with the aid of a microscope under the employment of magnifying powers from 7 to 35.

The table of the microscope carries a sliding apparatus, movable by a fine micrometer screw of 0.25^{mm} pitch, to which the negative is firmly clamped. The periodic and progressive errors of this screw have been accurately determined. By means of a large number of measurements in the solar spectrum it has been found that one revolution of the screw corresponds to a difference in wave-length of 0.324$\mu\mu$. With this value can now be computed g, the value in miles per second of velocity of one revolution of the screw, from the formula $g = \frac{\Delta\lambda}{\lambda} V$, where V is the velocity of light and λ the wave-length of Hγ, 434.07$\mu\mu$. The result is $g = 139.13$ miles. This value, strictly speaking, holds good only for the temperature at which this standard photograph of the solar spectrum was taken, since the dispersion varies with the temperature. A small correction has, therefore, been applied

to all the photographs made at a different temperature. For stars of the second type, however, a method of measurement has been chosen which takes for a basis this standard solar negative, as I shall presently show.

In the case of the spectra of Classes II. and III., containing numerous lines, it suggested itself, in determining the displacement between the artificial $H\gamma$ and the star line, to connect the former by differential measurements with the other neighboring lines, not only in order to obtain an increased degree of accuracy, but also indeed from necessity, since, in the generally very small displacements, it wholly or partly concealed the star line. All the difficulties which at first arose in the way of direct measurement of the plates, into the details of which I cannot here enter, were thereby overcome in that I simultaneously with the star spectrum also measured a standard solar spectrum taken with the spectrograph. The plate with the solar spectrum is cut off lengthwise, and so laid upon the star spectrum that the two appear in the microscope one above the other, and separated only by a small space.

The solar negative is observed through the glass, since, in order to avoid parallax, it must be inverted so that the two gelatine films are in contact. It is therefore cut off in order to obviate the effect of the unavoidable impurities in its gelatine film, through which otherwise the star spectrum would have to be observed. It can then be readily brought about that the lines of the one spectrum form the prolongation of those of the other.

The setting upon one of the threads of the system in the eyepiece of the microscope is effected solely by the motion of the above-mentioned sliding apparatus, to which both negatives are firmly attached. In the measurements four settings were usually made on a Sun line, then an equal number on the corresponding star line, those lines being sought out which, generally three on each side, lie nearest $H\gamma$. The $H\gamma$ line in the star has only been measured when it was fully separated from the artificial line; but generally, instead of upon it, settings were made six or eight times on the solar $H\gamma$, and an equal number on the artificial $H\gamma$ on the star plate.

The difference of the readings on the two spectra gives, in the mean, their displacement as compared with each other as they were brought together under the microscope; this mean, being applied to the difference of the settings on $H\gamma$ in the solar negative and the artificial $H\gamma$ due to the Geissler tube, gives the actual displacement of the star lines referred to the artificial line.

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In most cases the star spectra have been photographed at other temperatures than the Sun, and the differences Sun — star are unequal and show a rate of progression. Under the assumption of a simple proportional change, which is fully admissible for the small distances which alone come into question, a reduction to the dispersion of the solar negative must first be made, which has been done by the method of least squares.

The great advantage of this method of measurement lies in the fact that the unavoidable distortions in the sensitive film, which, owing to the smallness of the quantities to be measured, might easily come into consideration, are as much as possible eliminated, and also, further, that every prejudice of the observer is entirely eliminated, since the amount of the displacement is not directly obtained, but only after computation.

Most stars of the first spectral class show, in addition to the broad and strongly marked hydrogen lines, a great number of other lines, so fine, however, that they can be distinctly recognized only in the case of the brighter stars. The majority of these lines belong to the iron spectrum, and can be readily identified with solar lines; the measurement of the displacement can therefore either be made by reference to the solar negative, or, under the precautions which I have already stated in the article quoted, the iron spectrum may be used for comparison.

In the case of fainter stars of this class, however, one is restricted to the hydrogen lines, and if the more or less distinctly pronounced maximum of intensity lies outside of the artificial line, then the measurement presents no difficulty; but this is seldom the case, since the breadth of the maximum intensity corresponds to a difference in wave-length of about $0.03\mu\mu$, and a displacement of the artificial line only enough to bring its edge into coincidence with the position of maximum intensity would presuppose a velocity of fourteen miles. This maximum of intensity is generally not very sharply bounded, and, with this gradual decrease of the blackening on the negative, it could be accurately observed only in cases of a much greater displacement. The difficulties of this case were therefore insurmountable until a special procedure was thought out, which consisted in covering the $H\gamma$ star line, along with the artificial line, by a comparatively broad strip which was brought exactly over the middle of the $H\gamma$ line in the star. If, then, the thread of the micrometer be set on the middle of this strip, and the latter be then removed and the thread set on the artificial line, the difference in the readings will give the displacement.

The accompanying figure will make the procedure clearer. M M is the intensity curve of the star spectrum in the vicinity of $H\gamma$, K is the artificial $H\gamma$, displaced from the middle by the star's motion, and S is the strip covering the middle of the position of maximum intensity and the line K.

With a magnification such that the silver grains are readily perceptible, the setting of the strip over the middle of the broad $H\gamma$ line can, after some practice, be accurately accomplished by fastening the attention upon the density of the silver precipitate on the plate to right and left of the strip. From a series of small glass plates, upon each of which had been photographically produced a dark strip of differing width (from 0.05 to 0.20^{mm}), the suitable one was chosen and laid directly upon the star negative, and fastened by a simple mechanical contrivance which allowed of its being moved backwards and forwards by a fine screw.

When the line in the star spectrum has been very broad and without a distinct position of maximum intensity, I have employed still another method in the measurement of stars with large velocities. A number of lines of varying breadth and blackness, but narrower than the strips just mentioned, were photographed upon small glass plates, and that one was then selected which most nearly equalled in breadth and blackness the artificial $H\gamma$ on the negative to be measured. The plate was then laid upon the star negative, and by the fine screw set upon the broad star line, so as to be symmetrical with the artificial $H\gamma$. In the figure the star line is represented by the dipping of

the curve MM, K is the line from the Geissler tube, to which is symmetrically set the line S on the glass plate. The micrometric measurement of the distance KS gives the double value of the displacement. By practice much can here be gained in accuracy;

attention to the silver grains is in this case also important. It has shown itself to be of advantage to repeat the measurements on different days, since very soon a certain habit of perception sets in which gives the measurements on a single day the appearance of an accuracy which is somewhat illusory.

The first result of any importance which the spectrographic method furnished was the proof of the influence of the Earth's motion on the displacement, which the earlier direct observations had failed to show with certainty. I append here a few examples :—

α Aurigæ.

Date.	Obs. Vel.	Earth's Vel.	Vel. of Star red. to Sun.
1888 Oct. 6	− 3.5	− 15.4	+ 11.9
22	+ 2.9	− 13.0	+ 15.9
24	+ 3.8	− 12.6	+ 16.4
25	+ 3.5	− 12.4	+ 15.9
28	+ 3.8	− 11.8	+ 15.6
Nov. 9	+ 9.2	− 8.9	+ 18.1
Dec. 1	+ 10.8	− 2.9	+ 13.7
13	+ 15.6	+ 0.7	+ 14.9
1889 Jan. 2	+ 20.2	+ 6.6	+ 13.6
Feb. 5	+ 30.8	+ 14.3	+ 16.5
May 6	+ 33.2	+ 17.0	+ 16.2
Sept. 15	− 3.6	− 16.8	+ 13.2

α Tauri.

Date.	Obs. Vel.	Earth's Vel.	Vel. of Star red. to Sun.
1888 Oct. 28	+ 18.1	− 9.5	+ 27.6
Nov. 10	+ 24.9	− 5.9	+ 30.8
Dec. 4	+ 30.6	+ 1.8	+ 28.8
1890 Jan. 9	+ 43.7	+ 12.3	+ 31.4

α Ophiuchi.

1888 Sept. 30	+ 27.6	+ 14.1	+ 13.5
1889 June 7	+ 9.7	− 1.0	+ 10.7

α Ursæ Majoris.

1888 Nov. 7	− 17.0	− 11.9	− 5.1
9	− 18.1	− 11.9	− 6.2
1889 May 4	+ 5.2	+ 11.8	− 6.6
22	+ 3.4	+ 11.2	− 7.8

A further result of the new method was the discovery of the changes in the motion of Algol, and thereby the proof of the existence of a dark satellite, for the determination of which the most delicate measurements were necessary. The discovery of the periodic motion of α Virginis then followed.

As an example of the accuracy of the method of symmetrical setting, which has been applied for stars with broad and ill-defined lines, and generally in the case of α Virginis, I give here the results of the measurements, with the period which I have deduced from them :—

α Virginis. Velocity in the line of sight − velocity of system

$$= 56.7 \sin\left(\frac{t-t_0}{p}\right) 360°, \text{ in miles.}$$

Velocity of system = − 9.2 miles. Period, p, = 4.0134 days.

Epoch, t_0, = 1890 May 4, $10^h.50$ Potsdam M. T.

Date.	Obs. Vel. less Vel. of Translation	Calc. Vel.	O−C.
1889 April 21	− 48.4	− 53.5	+ 5.1
29	− 54.3	− 52.1	− 2.2
May 1	+ 50.7	+ 52.6	− 1.9
1890 April 4	− 6.5	− 12.4	+ 5.9
9	− 55.3	− 56.2	+ 0.9
10	+ 6.0	+ 10.6	− 4.6
11	+ 50.7	+ 56.2	− 5.5
13	− 57.6	− 56.2	− 1.4
15	+ 62.7	+ 56.2	+ 6.5
May 1	+ 53.5	+ 56.7	− 3.2

Date.	Obs. Vel. less Vel. of Translation	Calc. Vel.	O.—C.
1890 May 4	− 3.7	− 1.8	− 1.9
7	− 61.3	− 56.7	− 4.6
8	− 0.5	− 1.4	+ 0.9
9	+ 63.2	+ 56.7	+ 6.5
17	+ 61.8	+ 56.7	+ 5.1
18	+ 6.0	+ 5.5	+ 0.5
23	− 65.5	− 56.2	− 9.3
24	− 1.4	− 5.5	+ 4.1
25	+ 53.0	+ 56.2	− 3.2
May 26	+ 5.1	+ 5.5	− 0.4
27	− 52.6	− 56.2	+ 3.6
28	− 12.9	− 8.8	− 4.1
31	− 56.2	− 56.2	0.0
June 4	− 49.8	− 55.8	+ 6.0
1891 April 24	+ 3.2	+ 4.6	− 1.4
27	+ 47.9	+ 45.2	+ 2.7
May 3	− 58.1	− 63.2	+ 5.1

As an example of the delicacy of the spectrographic negatives, I remark that in those of β Aurigæ not only has the periodic doubling of the lines been perceptible and well measurable in the magnesium line $\lambda = 448\mu\mu$, but also on some plates in other very fine lines in its vicinity. These observations may be found in *Ast. Nach.*, No. 3017.

In order now to give an illustration of the accuracy which is attainable by the method of covering $H\gamma$ by a strip, I add my observations on α Lyræ and α Canis Majoris:—

α Lyræ.

	Obs. Vel.	Earth's Vel.	Star's Vel. red. to Sun.
1888 Sept. 28	− 2.6	+ 8.6	− 11.2
Nov. 11	− 1.7	+ 7.0	− 8.7
13	− 1.5	+ 6.8	− 8.3
1889 May 31	− 10.7	− 4.8	− 5.9
June 6	− 9.9	− 4.0	− 5.9
Sept. 15	− 1.8	+ 8.1	− 9.9
Nov. 24	− 4.2	+ 5.7	− 9.9
25	− 6.7	+ 5.6	− 12.3
26	− 7.2	+ 5.4	− 12.6

α Canis Majoris.

	Obs. Vel.	Earth's Vel.	Star's Vel. red. to Sun
1888 Dec. 13	− 14.1	− 4.9	− 9.2
1890 Feb. 12	+ 0.8	+ 9.4	− 8.6
1891 Feb. 7	+ 0.1	+ 8.3	− 8.2
Mar. 21	+ 4.4	+ 13.8	− 9.4
22	+ 6.1	+ 13.9	− 7.8

I remark, further, that the observations of Sirius by the method for stars of the second class give 7.3 miles, and with the aid of the iron comparison spectrum 9.0 miles as the rate of approach towards the Sun.

In regard to the exactness of the measurements in general I will state that out of the average of all the observations the resulting probable error of a single negative for stars of Class II. is ± 1.34 mile; for the stars of Class I. ± 2.31.

Each star has on the average been observed 3.3 times, and the measurements have been made independently by myself and by Dr. Scheiner. It may, therefore, be concluded that the probable error of the definitive values for both spectral classes will amount to less than one mile.

I intend after the definite completion of the measurements to communicate to the Society a list of the observed velocities, and will remark in conclusion that the velocities of the stars have

proved to be much smaller than was to be expected from the direct observations. The mean result for forty-seven stars is 10.6 English miles.

Among them six have a velocity less than 2, and five greater than 20 miles; the greatest is that of α Tauri, about 30 miles. Fifteen of the stars have a positive and thirty-two a negative motion.

POTSDAM, ROYAL OBSERVATORY,
1891 December.

NOTE ON THE STONYHURST DRAWINGS OF THE SOLAR SPOTS AND FACULÆ.*

REV. WALTER SIDGREAVES.

At the commencement of the series of Sun-spot drawings, instituted by the late Fr. Perry in November 1880, it was decided to fill in the faculæ, so far as this could be done with certainty. No small difficulty was experienced in the attempt, for it seemed impossible to produce a faithful representation of them, and both the director and the observer were forced to be content with a skeleton tracing of the brighter parts which could be differentiated from the rest of the photosphere without chance of error. Experience, however, in the course of time, taught the observer the magic effect of motion imparted to a faint image; and as he slowly travelled the image of the Sun across the drawing-sheet, the patches stood out with a clearness of definition that excluded all doubt of the border-line between faculæ and photospheric glare. The method then adopted, and followed ever since, was first to outline the brighter parts upon the stationary image, and then to fill in the picture by sketching the fainter details taken from the image while moving it slowly to and fro across the paper. By this means a very trustworthy record was obtained; and it was much improved by adopting the suggestion, made by Sir G. Stokes in 1883, that the contrast of a red-lead tracing of the faculæ would greatly help the eye in its search through the drawings for the true relation between the dark spots and their glowing attendants. This is apparent in following the disturbances through all their changes, and in sifting their evidences for an answer to the query, Which is the forerunner of the other?

During the entire period of Fr. Perry's direction of this

* Monthly Notices, December, 1891.

Observatory no clear instance of faculæ preceding the birth of a spot had been detected in the drawings. Faculæ were always most abundant after the birth of a spot, and always outlived it, lingering for weeks and sometimes for months before expiring. But, on the other hand, the drawings afford no positive evidence of the birth of a spot before the appearance of faculæ; while every spot of importance appears to have been attended from the beginning with at least a small surrounding of faculæ. So that, although it remains true that faculæ in no extensive form precede the birth of a spot, but develop and grow to maturity either along with the spot or after its decline, we must guard our conclusions against their extension to the absolute priority of the spot.

The chances of gaining the positive evidence about the priority are not favorable. The greater part of the Sun's surface, on which a spot may spring into life, offers no possibility of seeing the faculæ. And during the years of greater activity our chances are greatly reduced by the interlacing of old and new faculæ. It is only during the minimum period of spot-life, when the intervals are greater and old *debris* get cleared away before new storms begin, that we can well hope for the evidence we want.

The drawings of the recent minimum period of 1889 have been under careful study during the past twelve months, and we find amongst them two cases in which the evidence of first appearance is unquestionable. And both of these show faculæ before any trace of a spot appears.

On June 29, a small patch of faculæ was sketched near the eastern limb, in latitude $-40°.5$ and in longitude $252°$. There was no trace of a spot in the neighborhood, and neither spot nor faculæ had been seen near the position for years. On the following day a small round spot appeared in latitude $-40°.3$ and longitude $252°.2$—*i. e.*, in the midst of the faculæ, the faculæ on this day being visible only just close round the spot. Again, on July 31, another small patch of faculæ appeared in latitude $-22°$, longitude $155°$, without any spot near it. It was seen again on the following day, and still without a spot. But on the third day, August 2, a spot was sketched in latitude $-21°.9$, longitude $155°.4$.

In both cases the faculæ were of small area, but bright. And there can be no doubt either of the faculæ or of the spots. Both were new. The faculæ were not remnants, and the spots were not revivals of old disturbances. We may not be able yet to conclude that faculæ are really forerunners of spots. The two

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spots referred to may have been for the time hidden from our view by the faculæ. But this has no appearance of probability, the faculæ being seen at a distance from the limb of quite one-tenth of the solar diameter. So far, therefore, as our drawings at these dates are witnesses to priority, their evidence stands for some faculæ preceding the birth of a spot. And more of the same class of evidence may be found even in the years of greater spot frequency, when the records of their spots and faculæ have been more fully examined and the history of each group is more accurately written.

STONYHURST OBSERVATORY,
Lancashire.

RESUME OF SOLAR OBSERVATIONS MADE AT THE ROYAL OBSERVATORY OF THE ROMAN COLLEGE DURING THE FOURTH QUARTER OF 1891.*

M. P. TACCHINI, DIRECTOR.

	RELATIVE FREQUENCY		RELATIVE SIZE		
No. of days.	of spots.	of days without spots.	of spots.	of faculæ.	No. of groups per day.
October.....26	15.54	0.00	54.69	85.77	4.96
November...22	12.50	0.00	61.38	51.50	3.41
December....28	8.57	0.00	42.18	35.36	2.68

By comparing these data with the results of the preceding quarter, it is seen that the phenomena of solar spots and faculæ have decreased somewhat during the last quarter of the year. It must be remarked, however, that in the new series of observations there is not a single day without spots, and that the frequency of the groups is the same as for the preceding quarter; it may thus be concluded that we are now in a maximum spot period.

The season has been less favorable for prominences, especially in November. The following are the results obtained:

		PROMINENCES.	
	No. of days.	Mean number.	Mean height.	Mean extent.
October.....22	9.82	43″.6	1°.7
November.....15	5.73	35 .4	1 .6
December.....21	6.48	40 .2	2 .2

The marked frequency in the month of September continued into October; since then the number of prominences has somewhat diminished, so that for this quarter the phenomena of solar prominences may be considered as stationary relatively to the preceding quarter.

* Communicated by the author.

ON THE INFLUENCE OF PRESSURE ON THE SPECTRA OF FLAMES.*

G. D. LIVEING AND J. DEWAR.

We have already described (*Phil. Trans.*, A, 1888) the remarkable spectrum of the oxy-hydrogen flame burning at the ordinary atmospheric pressure. Recently we have examined the spectrum of the same flame at various pressures: hydrogen burning in excess of oxygen up to a pressure of 40 atmospheres, and oxygen in excess of hydrogen up to a pressure of 25 atmospheres, also that of the mixed gases burning in carbonic acid gas.

The apparatus employed was an adaptation of one of the tubes used in our experiments on the absorption spectra of compressed gases (*Phil. Mag.*, September, 1888, and *Roy. Soc. Proc.*, vol. 46, p. 222). It consisted of a steel cylinder, about 50^{mm} in internal diameter and 225^{mm} long, fitted at one end with a quartz stopper, *a* in the annexed figure, and with a jet, *b*, for burning the gas, adapted by a properly fitting union joint to the opposite end. There were two tubes, *c* and *d*, connected to the cylinder at the sides, of which one, *c*, served for the introduction of gas, while the other, *d*, was fitted with a stopcock, and was used to draw off the water formed, or to reduce the pressure of the gas in the cylinder if that was desired. The flame was observed, nearly end on, through the quartz stopper. The whole apparatus was kept cool by a stream of cold water running on to a sponge cloth wrapped around the cylinder. In the course of the tube conveying gas to the jet *b* was interposed a small cylinder, *e*, in which sodium was placed, and by heating this the gas entering could be charged with sodium vapor.

The gases were supplied from steel cylinders into which they had been compressed, and the pressure was registered by a gauge attached to the tube by which the gas entered the experimental cylinder. Commercial compressed gases were used, containing a sensible percentage of air.

When hydrogen was the gas forming the burning jet, it was lighted at the end of the tube *b* before introducing it into the experimental cylinder. When it was desired to have a jet of oxygen burning in hydrogen, this could be managed by introducing oxygen through the second tube and increasing the supply of hydrogen until the flame passed over to the oxygen jet. The same result was sometimes attained by first filling the experi-

* Proceedings Royal Society, No. 298.

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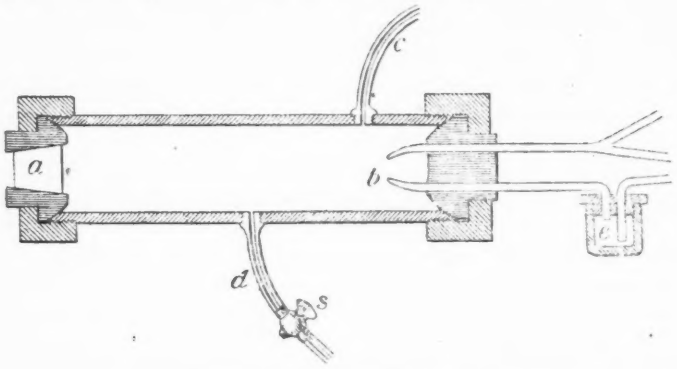
mental cylinder by a gentle stream of hydrogen through the side tube *c* before the end with the tube *b* was screwed on; the hydrogen as it issued was then lighted, and the jet, with a gentle stream of oxygen issuing, inserted and screwed down. The stopcock *s* was kept open until this was done, and then by closing *s*, and admitting more gas from the reservoirs, the pressure in the experimental cylinder could be increased at pleasure.



Hydrogen Burning in Oxygen.

The first observations were made with a jet of hydrogen burning in oxygen. As the pressure rose, the luminosity of the flame increased, as long ago described by Frankland ('Experimental Researches,' p. 905). The color of the flame, viewed end on, was yellow, as if it contained sodium; but, on examining it with a spectroscope, it was found to give a continuous spectrum intersected by many shaded bands, and the D lines of sodium were only faintly present. The shaded bands were faint at a pressure of 5 atmospheres, but at pressures of 20 atmospheres and upwards they came out strongly. They were evidently the absorption bands of NO_2, derived from the residue of atmospheric air mixed with the condensed gases. We took a photograph of them, and on comparing this with a photograph of the NO_2 bands, we found the two to be identical. Except for the bands, and the bright lines of sodium, the spectrum appeared to be continuous, and to extend from about λ 6200 to λ 4150, with the brightest part about λ 5150. It increased in brilliance as the pressure increased, as well as in extent, being visible at 3 atmospheres pressure from about λ 6720 to λ 4040. The greater distinctness of the NO_2 bands at the higher pressures was due both to the greater brightness of the continuous spectrum and to the

greater quantity of NO_2 formed. A large quantity of water accumulated in the experimental tube, and when this was drawn off by the stop-cock s it effervesced with escape of NO, and was found to be strongly acid. A specimen titrated was found to contain very nearly 3 per cent of nitric acid. The observations were continued up to a pressure of forty atmospheres. There was no indication that the continuous spectrum had any connection with the line spectrum of hydrogen. There was no increase of brilliance in the neighborhood of the C, F, or G lines of hydrogen. The characters of the spectrum were, however, better seen in the absence of NO_2, and will be described in the next section.

Oxygen Burning in Hydrogen.

In this case the color of the flame was very different from that of hydrogen burning in oxygen. Instead of being yellow, it appeared, to the unaided eye, to have a lavender hue. In the spectroscope it showed a perfectly continuous spectrum, brightest in the green, about the region of the Fraunhofer line *b*, and very gradually fading away on either side. On the red side it could be just traced up to about λ 6150, and on the violet side to about λ 4285, at ordinary pressures. The sodium lines were absent. With increase of pressure it increased very much in brightness, and at 8 atmospheres pressure it could be traced as low as λ 6630 and as high as λ 3990.

The dispersion used was that of a direct-vison spectroscope (such as was described by us, *Roy. Soc. Proc.*, vol. 41, p. 449), equivalent to three prisms of white flint glass, but the collimator and telescope very short, so as to obtain plenty of light. With less dispersion, perhaps, the continuous spectrum might have been traced further. Photographs, however, showed that it scarcely extended into the ultra-violet. There was no indication that this spectrum was due to an expansion of the lines of either the first, or second, spectrum of hydrogen. It is true that the maximum brightness (which could not be determined with any great accuracy) was not very far from F, but no indication of any second maximum in the neighborhood of either C or G, or anywhere else, could be detected. The pressure was carried up to 12 atmospheres, and at this pressure the visible spectrum was brilliant, but, in the ultra-violet, photographs showed that the spectrum consisted only of what we have called the "water-spectrum," very strong and sharp. The lines of this spectrum showed no signs of expansion even at a pressure of 12 atmospheres, and, though much more intense than at ordinary pressures, remained clearly defined.

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Observations were continued with the eye up to 25 atmospheres pressure, but no trace of emission, or absorption, corresponding to either spectrum of hydrogen could be detected, and it is doubtful if either spectrum can be produced in such a flame. Since the formation of steam from its component gases is attended with a diminution of volume, increased pressure will increase the stability of the compound, and the flame will contain a larger proportion of steam, as well as have a higher temperature, than at ordinary pressures.

The water formed when the flame was a jet of oxygen burning in hydrogen was found to be alkaline, and to contain ammonia. But the proportion of ammonia was much less than the proportion of nitric acid formed when the jet was hydrogen burning in oxygen; a specimen titrated contained 0.004 per cent of ammonia.

Effects of Pressure on the Sodium Spectrum.

In order to see what effect would be produced by increased pressure on the spectrum of other substances in the flame, we charged the hydrogen with sodium vapor by making it pass, before entering the experimental cylinder, through a small iron cylinder, *e* in the figure, containing metallic sodium, heated by a lamp. As the D lines of sodium are very easily expanded and self-reversed in a flame at ordinary pressure, some care was needed to discriminate the effects, which were really to be ascribed to pressure. The gas was easily charged with sodium vapor, and when burning in oxygen, not only the D lines, but the citron and green pairs, and sometimes the blue pair (λ 467), and the orange pair (λ 616), were well seen; but we could not find that they were expanded by increase of pressure. A sudden change of pressure generally produced an expansion, but it did not last; the lines fined down again when the pressure was steady, whether that pressure was high or low. These experi- continued up to a pressure of forty atmospheres without any definite effect on the width of the lines which could be ascribed to the pressure.

It may be said that at the higher pressure the evaporation of the sodium would be slower, and so the proportion of sodium vapor to hydrogen be diminished; also when the lines are diffuse at the edges to begin with, it is extremely difficult to judge whether there is any expansion. At all events, we may say that there is no expansion produced by pressure at all comparable with that produced in a flame at ordinary pressure by increasing

the quantity of sodium in the flame. We noticed, however, that the presence of sodium, which produces a feeble continuous spectrum in a flame at an ordinary pressure, seemed to increase the continuous spectrum of the flame under pressure, especially in the orange and green.

Oxy-Hydrogen Jet in Carbonic Acid Gas.

For this experiment a two-branched tube (the upper one in the figure) was used. The jet of mixed oxygen and hydrogen was first lighted and introduced into the experimental cylinder, while the latter was full of air and the stop-cock *s* open. The air was then replaced by CO_2 entering by the tube *c*. The effect of this was at once to brighten the flame and change its color from yellow to blue. Seen in the spectroscope, the change consisted in an increase of continuous spectrum, especially towards the more refrangible end. When the stop-cock, *s*, was closed so that the pressure rose in the experimental cylinder, the flame increased in brightness, but there was no other change in the spectrum. It remained continuous with no bright or dark lines, or bands, except the D lines of sodium. It resembled an ordinary flame of CO. The jet would not burn in CO_2 unless there was some excess of oxygen, and even with an excess of oxygen we could not get it to continue to burn in CO_2 at a pressure higher than two atmospheres.

Ethylene in Oxygen.

A jet of ethylene burning in oxygen gave, when the flame was small, the usual candle flame spectrum, together with a band in the indigo (λ 431) shading towards the violet; but as the pressure was increased the continuous spectrum brightened and completely overpowered the bands, and at the same time the absorption spectrum of NO_2 appeared. We carried the pressure up to 33 atmospheres, and at that pressure the flame seemed to give nothing but a continuous spectrum, intersected by the absorption bands of NO_2. In our tube, the flame was viewed almost directly end on, and it is possible that if we had seen the flame sideways, we might have detected the hydro-carbon flame spectrum near the nozzle. At the high pressure much soot separated. We tried burning a mixture of ethylene and oxygen. The mixed jet burnt well in air and, when the supply of oxygen was sufficient, gave the hydro-carbon flame spectrum. In the experimental tube in oxygen the jet burnt well at the atmospheric pressure, but we failed to get it to continue burning when the pressure was in-

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creased. The shaded band, commencing with a sharply defined edge about λ 431, seems to be independent of the pressure, and has been before observed in a gas flame (Huggins, *Roy. Soc. Proc.*, vol. 30, p. 580). In fact the only effect of pressure in this, as in the former cases, seemed to be the increase of the continuous spectrum.

Cyanogen and Oxygen.

As we could not obtain cyanogen at such pressure as we had used in the case of the other gases, we were obliged to content ourselves with exploding mixtures of cyanogen and oxygen in an iron bottle, fitted with a quartz stopper like that of the experimental tube above described. The bottle, having been exhausted by an air pump, was filled with the mixture of gases, and exploded by an electric spark. With less than 3 vols. of oxygen to 1 vol. of cyanogen, there was always a considerable deposit of carbon, which covered the quartz and impeded vision; but with 3 vols. of oxygen to 1 of cyanogen the carbon was all burnt. Notwithstanding the brilliant banded spectrum of a flame of cyanogen in oxygen at ordinary pressure, nothing but a continuous spectrum could be seen in the flash of the exploded gases, except the ubiquitous D lines of sodium. The continuous spectrum was bright. Photographs showed a continuous spectrum with lines of iron, calcium, potassium, and sodium, but no cyanogen or carbon bands, or carbon lines. When a little hydrogen was added to the mixture of gases, no trace of the hydrogen red or green line could be detected in the spectrum of the exploding gas.

In every case, the prominent feature of the light emitted by flames at high pressure appears to be a strong continuous spectrum. There is not the slightest indication that this continuous spectrum is produced by the widening of the lines, or obliteration of the inequalities, of the discontinuous spectra produced by the same gases at lower pressures. On the contrary, it seems to be developed independently. This is, on the whole, quite in accordance with what would be expected, considering that under pressure the molecules of the gases have much less freedom, encounters amongst them are much more frequent, and they have much less chance of vibrating independently, and of taking up exclusively, or chiefly, the fundamental rates of vibration which are natural to them when free. Their condition, during a large part of any given time, approximates to that of the molecules of a liquid, and their spectra approximate to that of a liquid to at least a like extent. On the other hand, the

higher temperature which, in many flames, attends an increased pressure, ought to give some intensity to the special radiation which the molecules emit during their time of free motion; and this we have noticed to occur in the principal sections of the discontinuous spectrum of the oxy-hydrogen flame. Whether the continuous spectrum is due to the mutual action of the molecules of the compressed gases may perhaps be best determined by some photometric measures of the rate at which the brilliance increases with the pressure. Frankland ('*Exp. Researches*,' pp. 892 *et seq.*) has made some such measures, but not sufficient to solve the question. We have made an attempt to measure, not the total intensity of the light, but that of rays of definite refrangibility.

Photometry of Oxy-Hydrogen Flame under Pressure.

The apparatus used for these measures was a spectro-photometer of the pattern employed by Crova (*Annales de Chimie*, ser. 5, vol. 29, p. 556). In this, the rays of one of the sources of light to be compared are passed through two Nicol's prisms, and then reflected into one-half of the slit of the spectroscope, while the light from the other source passes directly into the other half of the slit. By turning one of the Nicol prisms, the light from the first source can be reduced at pleasure, and any small section of the spectrum can be separately observed by cutting off the rest by means of a shutter in the eye-piece. We found it by no means easy to get good concordant observations. A much larger vessel was used than for the earlier experiments, one which contained several litres, and so we may presume a more uniform pressure was maintained within it. The results of the best series of observations on the photometric intensity of the jet of oxygen burning in hydrogen are given in the following table. The comparison light was a petroleum lamp.

1.	2.	3.	4.
15 lbs.	3°	274	$30 \times 3^2 = 270$
35	7	1485	$30 \times 7^2 = 1470$
55	11	3641	$30 \times 11^2 = 3630$
75	14	5853	$26 \times 15^2 = 5850$
95	19	10600	$29 \times 19^2 = 10469$

The first column gives the pressure of the gas, the second the mean of four to six observations of the angular deviation of the Nicol's prisms from the position of complete extinction, for each pressure. The third column gives the squares of the sines of the angles in the second column multiplied by 100,000.

It will be seen from the last column that the numbers in the third column, which should be proportional to the photometric

intensities at the respective pressures, are approximately proportional to the squares of the pressures.

This may be taken to indicate that the brightness of the continuous spectrum depends mainly on the mutual action of the molecules of gas.

A series of similar observations on hydrogen burning in oxygen gave somewhat different results, tabulated below:

1.	2.	3.
15 lbs.	6°	1093
35	13	5060
55	18	9549
75	22	14033
95	28	17861

The flame was brighter than that of oxygen burning in hydrogen at ordinary pressure, but the rate of increase with increased pressure was not so rapid as in the former case. It seems as if the continuous spectrum were made up of two parts, one varying as the square of the pressure, and another according to some other law. The flame is evidently not the same in the two cases. The products of combustion derived from the small quantity of air are different, and also the hydrogen jet always showed the presence of sodium, sometimes calcium. The appearance of the flame was also different; the hydrogen jet being faintly visible and yellowish in the elongated part, whereas the light from the oxygen jet was concentrated near the base, the point being invisible. The measures of which the means are tabulated above were also less concordant than the corresponding measures for the oxygen jet. We were unable to carry our measures beyond a pressure of 95 pounds, because at higher pressures a cloud was formed in the apparatus which prevented our seeing the flame directly. We hope to prosecute these measures with flames of other gases, and, if possible, at higher pressures.

The conclusions to which our experiments have led seem inconsistent with those which have been drawn from Plücker and Hittorf's well-known observations on the widening of the hydrogen lines in vacuous tubes with a residue of hydrogen when that residue increases. That the widening of the lines in a Plücker's tube results from increasing the density of the residue of hydrogen in the tube cannot be gainsaid, but we are wholly ignorant of the mechanism by which the gas is lighted up by the electric discharge. It is sometimes assumed, but without any sufficient reason, that the energy of the electric current is first converted into heat, and then in turn into radiation; but the electric energy may equally well be directly converted into the motion of

radiation. As a fact, we have never yet been able to obtain either the emission or the absorption spectrum of hydrogen without the aid of an electric current, so that, in reasoning on this spectrum, we are much more in a region of speculation than when treating of flames. Whether the hydrogen lines, bright or dark, in the solar spectrum are produced directly by the high temperature of the Sun, may even be called in question. And though we may admit that the density of the hydrogen in the Sun's atmosphere, outside the photosphere, is but slight, it does not follow that the total pressure of all the gases forming that atmosphere is so very small as Messrs. Franklin and Lockyer ('*Roy. Soc. Proc.*,' vol. 17, p. 288) have, from the width of the lines, concluded it to be. After all, it is not so easy to connect the temperature, even of a flame, with its radiation, for it is only when the condition of a gas is steady that we can assume that there is a definite relation between the motion of agitation, on which temperature depends, and the vibratory motions on which radiation depends. In speculating on such questions, chemical, as well as electrical, changes must not be lost sight of although the latter may be more directly concerned in radiation.

Experiments which we have commenced upon the arc in an atmosphere of compressed gas tend to the same conclusion. It does not appear that the metallic lines in the arc are sensibly affected by a steady pressure up to 15 atmospheres. The details of these observations, which are complicated by the variation of resistance with change of pressure, we defer until the experiments are finished.

ON THE PHYSICAL CHARACTERS OF THE LINES IN THE SPARK SPECTRA OF THE ELEMENTS.*

PROFESSOR W. N. HARTLEY, F. R. S.

The properties of the atoms are a periodic function of their masses, and the physical characteristics of the spectra of the elements appear to be an expression of the properties of the atoms; for there is undoubtedly an intimate connection between the rays emitted by the self-luminous vapors of the elements and their chemical and physical properties.

If we photograph the spark spectra of thirty or forty of the elements and arrange the spectra in groups following the periodic law, the arrangement will be seen to be a perfectly nat-

* Proceedings Royal Society, No. 300.

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ural one. This observation applies not only to the groupings of the lines, but also to the physical characteristics of the individual lines. In spark spectra the three most striking characteristics are (1) an extension of certain lines above and below that part of the spectrum bounded by the points of the two electrodes; (2) the nimbus which surrounds the extremities of the lines, even to some extent those portions which form an extension; and (3) the continuous spectrum which forms the background to the lines.

(1.) *On the Extension of the Lines.*—The spark discharge, as shown by Perrot, is composed of two parts, of which the fiery track, or central portion, is a statical discharge, and the aureole, or flame, is dynamical, and capable of electrolytic action.

From careful observation of the sparks, and photographs of spectra, I have come to regard all those spectra with lines extended as spectra of different discharges taken simultaneously. The principal lines lying between point and point of the electrodes are spectra of the fiery path of the spark; the extension of the principal lines above and below the points of the electrode appear to be spectra of the aureole. The principal observation which leads to this conclusion is that the electrodes are seen to glow silently and continuously above and below the points of the upper and lower electrodes, and frequently slight roughnesses present the appearance of brightly but steadily shining dots; particularly is this the case with those metals which exhibit the most extended lines, as, for instance, cadmium, thallium, and indium. The lines in many spectra are free from this extension, and no glow is observed on the electrodes. A study of about thirty different spectra of the metals and semi-metallic substances has led to the following observation.

Elements which are difficult to volatilise, and those which are bad conductors of electricity, do not exhibit spectra with extended lines; and, conversely, metals which are the best conductors and the most volatile exhibit spectra with their principal lines largely extended.

The following metals are good conductors, that is to say, sufficiently good not to impede the spark when broad electrodes are used, and they are more or less volatile. They show a large extension of their principal lines:

	Boiling point.	Atomic mass.		Volatility.	Atomic mass.
Magnesium.	1100° C.	24.4	Aluminium.	Not volatilised by ordinary means.	27.08
Zinc.....	924° to 954° C.	65.3	Indium.....	Volatilised at a red heat.	113.7
Cadmium....	763° to 722° C.	112.1	Thallium....	Easily Volatilised at a red heat.	204.2

		Atomic mass.
Copper.....	Not volatilised by ordinary means.....	63.33
Silver.....	Boils about 1570° C.....	107.93
Mercury.....	Boils about 357° C.....	200.1

In these examples the extension of lines is least in the case of the least volatile metals, which are also those of least atomic mass, and it is greatest with those which are most volatile and of greatest atomic mass.

The continuous spectrum in these examples is very weak, and the air lines are almost absent from the thallium and mercury spectra, the air spectra being suppressed by the excess of dense vapor in the track of the spark. The lines most extended are the following: In the cadmium spectrum, those with wave-lengths $\overline{3611.8, 3609.6}$ (*a pair*), $\overline{3466.8, 3465.4}$ (*a pair*). These pairs appear as single lines if the dispersion is insufficient and the definition imperfect.

The most refrangible line of each pair is the more extended. The other lines in this spectrum are 3402.9, 2747.7, 2572.2, 2313.6, and 2265.9, all with fine extensions. In the spectrum of thallium, wave-lengths 3775.6, 3528.8, 3518.6, and 2917.7.

In the spectrum of mercury, the lines with wave-lengths 4358, 4046.5, and 3984 are well extended, but the most important extensions in this spectrum are the lines with wave-lengths 3662.9, 3654.4, 3632.9; the last of these, which form a well-marked triplet, is by far the most extended. The pair of lines 3130.4 and 3124.5 are greatly extended, and the same remark applies to 2966.4 and 2946.6.

The dimensions of the principal lines in the cadmium, thallium, and mercury spectra were measured on my enlargements. The principal portion of the lines lying between point and point of the electrode was 42 mm. in all spectra. The extension of the lines *below* was 22 mm. to 25 mm., extension *above*, 9 mm. to 10 mm. As the extension is always sharp and well-defined, it is an important feature in these spectra. Even concentrated solutions of the metals, when photographed with graphite elec-

trodes, exhibit this extension in their principal lines. For instance a solution of beryllium chloride shows a very remarkable extension above and below the points of the upper and lower electrodes; the dimensions of the principal line, wave-length 3130.2, are as follows: between the points, 42 mm., *below*, 10.5 mm.; *above*, 17.5 mm. It is at the upper or positive electrode that the longest extension is observed, but at the lower or negative electrode that it is strongest. In the case of the cadmium lines, the extension is smaller, but strong at the side of the negative electrode, and very fine and long at that of the positive.* The appearance of lines due to impurities or traces of metals in the spectrum of the negative electrode only, I have attributed to the oscillation of the spark discharge, and the fact that the negative electrode is the hotter.†

(2.) *The Nimbus.*—The nimbus is not apparently dependent on the volatility or the oxidisability of the vapor of the elements, though these properties are connected therewith.

By far the largest nimbus is that of magnesium; those of cadmium and mercury stand next in order; the smallest are those of platinum, gold, copper, and silver. It is thus evident that neither conductivity nor vapor density controls it, for there is very little nimbus on the lines of the thallium and iridium spectra; but volatility certainly increases it. There is a considerable nimbus on some of the lines in the spectra of arsenic, antimony, and bismuth; also on a few lines of tin and of lead. In the case of magnesium, the cause of the dense and large nimbus is probably the intensity of the chemical action of which the rays of the incandescent vapor are capable, together with the large quantity of metal in the track of the spark, owing to its volatility.

The chemical activity of the zinc rays is less than that of the rays of magnesium, but the effect of this is overbalanced by the density of the vapor and the volatility of the metal being both greater; accordingly the lines of zinc have a large nimbus. The nimbus is somewhat larger on the lines of cadmium than on those of zinc, the volatility and the density of the vapor are both greater.

The nimbus is evidently an expression of the quantity of matter in the spark, and the intensity of the chemical action which the rays emitted by its ignited vapor are capable of exerting.

* In a paper published in the 'Scientific Proceedings of the Royal Dublin Society,' on the constitution of electric sparks, this does not appear in the lithographed illustration, but I have carefully verified the fact by referring to the original photographs.

† *Loc. cit.*, p. 373.

(3.) *On the Continuous Spectrum which forms the Background to the Lines of certain Spectra.*—This must be caused by the ignition either of some solid substance or of a vapor which is not that of an element but an oxide. An examination of the spectra in which the continuous background of rays is a conspicuous feature discloses the fact that the metals which are not oxidisable do not possess it, for instance, gold, silver, and platinum. Metals of the iron group show it near the points of the electrodes when the non-volatile oxides are formed. The very volatile metals with volatile oxides, such as mercury, iridium, thallium, zinc, and cadmium, do not show it.

Spectra of the metalloids, such as tellurium, arsenic, antimony, and bismuth, which are not only volatile but which form volatile oxides, show it very strongly. Ordinarily, magnesium does not show it, because the exposure necessary for photographing the spectrum of that element is less by one-half the period of the others, and by one-quarter that of tellurium. When a plate is long exposed to the rays of magnesium, the continuous spectrum appears at the points of the electrodes where the non-volatile oxide would be formed. It may be considered that in the passage of the spark, the vapor of the element fills the track, and this vapor, on cooling, forms, for a minute period of time, an incandescent oxide, and, the spectrum of this being a continuous spectrum, its photograph appears as a background to the rays emitted by the element.

But it is nevertheless the fact that the continuous background is a very characteristic feature of the metalloids, though why the vapors of these oxides should produce this action more conspicuously than those of the oxides of the volatile metals, there seems to be no sufficient or well-understood reason to be advanced at present. It may be that the vapors of the metalloids in cooling emit a continuous spectrum for a short period prior to oxidation.

On the Breadth of Lines.—It is well known that under identical conditions, the principal lines in the spectrum of an element become stronger and broader as the rays forming the spectrum proceed from a larger quantity of material, that is to say, form a denser radiating layer. It is evident, then, that in any series of three or more elements of similar character, the intensity and the breadth of the lines in their spectra will depend upon (1) intensity of chemical energy, (2) volatility and vapor density, and (3) electric conductivity of the metal. In accordance with these conditions, the lines of cadmium are broader than those of zinc, and the lines of zinc broader than those of magnesium.

THE NEW STAR IN AURIGA.*

EDWARD C. PICKERING.

The photographs of the Henry Draper Memorial afford a means of studying the past condition of the portion of the sky in which the new star in Auriga has recently been discovered. Eighteen photographs of this region were taken with the 8-inch photographic telescopes from November 3, 1885 to November 2, 1891.

On none of them was the star visible, although on all but five, stars of the eleventh magnitude were shown, and on some of them stars of the thirteenth magnitude were visible. On the plate taken November 2 spectra of stars of the eleventh magnitude were shown. It is probable that the star was not visible during these six years. Five plates, on the other hand, taken from December 16, 1891, to January 31, 1892, show stars of the twelfth magnitude and the Nova appears as a bright star of the fifth magnitude. A still closer watch of the sky has been kept for the past year with an instrument intended to furnish the scale of stellar magnitudes of the brighter stars to which the stars photographed with the Bruce 24-inch photographic telescope will be referred. This instrument is called the transit photometer. It consists of a telescope having a Voightländer doublet of five inches aperture as an objective mounted like a transit instrument and driven automatically by clockwork in such a way that a region extending from 30° below the north pole to 30° in declination and in right ascension over three hours will be photographed on one plate.

The exposure given to each portion of this region is two seconds, and in this time stars of the sixth magnitude and brighter are distinctly shown. Plates were thus obtained on thirteen nights from October 21 to December 1, 1891. On none of these was the star visible, although χ Aurigæ, magnitude 5.00, was always clearly shown. On twelve nights beginning December 10, 1891, and ending on January 20, 1892, similar plates were obtained, on all of which the new star was clearly seen. Measurements of these images were made by Mrs. M. Fleming who also made the examination of the photographs described above. The Nova was compared directly with χ Aurigæ, and the difference in brightness estimated in grades as in Argelander's method of observing variable stars.

* Communicated by the author.

To secure independence in the measurements an assistant recorded the numbers of the plates and the measures, rearranged their order according to chance, and returned them to Mrs. Fleming to be measured again. A third measure was made in the same way. On December 10, 11, 18, 28, and 30, 1891, and on January 5, 8, 9, and 16, two photographic images of the star were obtained. On December 17 and 18 the first measures were repeated. The corresponding dates, magnitudes and residuals expressed in tenths of a magnitude are given in the following table:

Date	Magn.	Residuals.
1891 December 10	5.37	0 −1 −1 0 0 0
" 11	5.33	0 0 0 +1 +1 0
" 13	5.22	0 0 0 +1 0 0
" 17	4.67	0 0 −1 −1 0 0
" 18	4.46	−1 −1 −1 +1 0 +1
" "		−2 −2 −2 −1 +1 +2
" 28	4.55	0 −1 −1 0 0 −1
" 30	4.60	−1 +1 0 −1 +1 0
1892 January 5	4.58	−1 0 +1 −1 −1 +1
" 8	4.72	0 0 0 +1 0 0
" 9	4.67	0 +1 −1 −1 0 −1
" 16	4.96	0 0 0 0 0 0
" 20	5.23	+1 0 0

The accordance of the measures is shown by the average residual which equals ± .05. From this it appears that the star was fainter than the eleventh magnitude on November 2, 1891, than the sixth magnitude on December 1, and that it was increasing rapidly on December 10. A graphical construction indicates that it had probably attained the seventh magnitude within a day or two of December 2, and the sixth magnitude December 7. The brightness increased rapidly until December 18, attaining its maximum about December 20 when its magnitude was 4.4. It then began to decrease slowly with slight fluctuations until January 20 when it was somewhat below the fifth magnitude. All of those changes took place before its discovery, so that it escaped observation nearly two months. During half of this time it was probably brighter than the fifth magnitude.

Since the announcement on February 2 of its discovery it has been closely followed at this Observatory both visually and photographically. Comparisons by Argelander's method visually are made every clear night by Mr. O. C. Wendell and Mr. W. M. Reed. Comparison stars have been selected so as to form a sequence having intervals of three or four tenths of a magnitude. Their numbers, positions for 1855.0 and magnitudes according to the Durchmusterung are given below when they occur in that catalogue. In other cases the positions have been determined

directly. The first of these stars is 16 Aurigæ, the second χ Aurigæ. The faintest star *w* is of the twelfth magnitude.

Design.	D. M.	No.	R. A.	Dec.	Magn.
			h m s	°	
a	+ 33°	1000	5 8 39.8	+ 33 13.1	5.1
b	+ 32°	1024	5 23 18.4	+ 32 4.8	4.8
c	+ 33°	1013	5 10 28.7	+ 33 48.1	5.9
d	+ 29°	869	5 11 59.6	+ 29 25.4	6.0
e	+ 30°	898	5 17 51.4	+ 30 4.2	6.2
f	+ 29°	947	5 30 5.9	+ 29 7.6	6.2
g	+ 29°	909	5 20 27.9	+ 29 3.9	7.0
h	+ 27°	806	5 26 50.0	+ 27 33.7	7.1
k	+ 32°	1003	5 19 52.8	+ 32 4.8	7.4
l	+ 31°	1001	5 23 20.4	+ 31 55.0	7.6
m	+ 31°	989	5 20 56.5	+ 31 40.8	7.7
n	+ 30°	912	5 20 27.2	+ 30 28.4	8.5
o	+ 30°	913	5 20 48.6	+ 30 19.8	8.7
p	+ 30°	918	5 21 55.6	+ 30 3.9	9.3
q	+ 30°	914	5 20 48.8	+ 30 28.0	9.4
r			5 22 36.8	+ 30 27.5	
s			5 22 43.6	+ 30 21.2	
t			5 22 45.3	+ 30 26.2	
u			5 22 54.7	+ 30 18.3	
w			5 22 43.6	+ 30 29.4	
Nova			5 22 40.3	+ 30 19.9	

The magnitudes of all these stars will be determined photometrically for use in the final reduction. On every clear night Mr. Wendell also compares the Nova with the star s in the list given above. These observations are made with the 15-inch equatorial by means of a polarization photometer (H. C. O. Annals XI, Part I). Measures of the Nova and of the brighter comparison stars are made by Mr. S. I. Bailey and the writer with the meridian photometer. Five independent series of visual observations will thus be obtained which will test the reality of any apparent fluctuation. The position of the Nova with regard to Weisse 5^h 709 which is DM. + 30° 9 ¦2, has been determined by Mr. Wendell with the 15 inch equatorial. The dates, the resulting differences in right ascension and declination, and the position for 1900.0 are given below.

Date 1892	$\Delta\alpha$	$\Delta\delta$	α 1900.0	δ 1900.0
	m s	′ ″	h m s	° ′ ″
Feb. 4	− 1 48.20	− 6 21.2	5 25 33.40	+ 30 22 13.2
Feb 6	− 1 48.29	− 6 19.9	5 25 33.31	+ 30 22 14.5
Feb. 9	− 1 48.33	− 6 20.3	5 25 33.27	+ 30 22 14.1
All	− 1 48.27	− 6 20.5	5 25 33.33	+ 30 22 13.9

Photographic charts are made every clear evening with the 8-inch Draper telescope, and photographs are also taken with the transit photometer.

An important series of photographs of the spectrum is being obtained with the 11-inch Draper telescope, and since the star

will probably soon be too faint to photograph in this way, spectra are also taken with the 8-inch telescope using a small dispersion. The spectrum can thus be photographed until the star is as faint as the eleventh magnitude. With these last photographs several lines, including F, G, h, K, and a, appear to be bright. But on closer examination they are shown to be really dark with the edge of greater wave-length bright. This is confirmed with the greater dispersion, the bright lines really consisting of broad bands sharply defined on the edge of smaller wave-length. The breadth of the bands is not due to poor definition since numerous fine lines are also visible. Many of the lines, including the K line and those due to hydrogen are double. The evidence that this doubling is due to the different velocities of different portions of this object is not conclusive owing to the breadth of the bands. The difference in velocity indicated by the separation of the lines is about 370 kilometers per second. The apparent separation of the different lines in the photograph increases as the wave-length diminishes, as it should according to this theory owing to the increasing dispersion of the violet rays. Two explanations have been offered of the sudden increase in light of stars of this class—the mechanical theory that it is caused by approach or collision, and the chemical theory that it is due to volcanic action. The doubling of the lines strengthens the first of the above theories rather than the second.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., February 15, 1892.

ON THE VISIBLE SPECTRUM OF THE NEW STAR IN AURIGA.*

HENRY CREW.

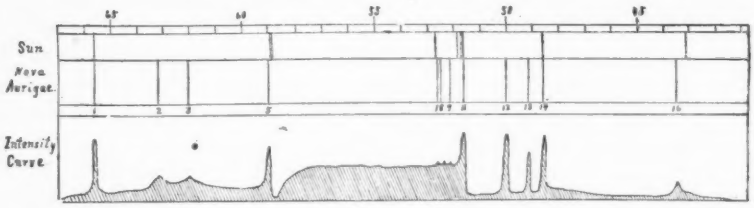
The following is only a *preliminary* general description of the spectrum of Nova Aurigæ, whose appearance was announced at this Observatory on the 6th of February, 1892. The observations cover two evenings, Feb. 10th and 11th, and were made with the spectrometer attached to the 36-inch.

The wave-lengths, while in no sense final, will be found much more accurate than necessary to identify the lines, and will furnish a hint as to the identity of some of them with known lines. The positions were determined by comparison with the lunar and spark spectra. The wave-lengths of the principal lines are given

* Communicated by the author.

in the following table. The values for lines 11 and 14 are more accurate than the others, these having been measured with a 14,438-line grating in the third order: line No. 11 was compared with b_4 of the magnesium spark, and line No. 14 with F of the hydrogen tube.

The remaining lines were determined by the use of a compound prism. The numbers of the lines correspond with those in the accompanying diagram, which, taken with the light curve underneath, will give some idea of what can be seen with the eye.



Line.	Wave-length.	Description.
1	6565.8	Probably C: very broad and bright in prism: not seen in grating: more brilliant than C line in Phi Persei, but not so bright or sharp as C in Gamma Cassiopeiæ, when this last star is at its brightest
2	6321.	Faint, broad, diffuse.
3	6209.	Not quite so bright as 2: but broader: both 2 and 3 may be bright only in comparison with neighboring absorption bands.
5	5898.	Yellow line, just below D_1: intensity diminishes very rapidly on the side towards the violet: at times this edge appears very sharp: just above this line there is a rather narrow, dark, absorption band, suspiciously near D.
7	5265.	Three very faint lines: difficult to say whether they are really bright lines or simply bright regions bounded by dark spaces.
8	5254.	
9	5216.	
11	5167.1	Much more brilliant than any of the preceding: quite broad: much sharper on the upper side than the lower: nearly coincides with b_4. The most brilliant part of the continuous spectrum is terminated abruptly by this line.
12	5009.	Of about the same brilliancy as 11: and, like it, sharper on the upper side. Nebular?
13	4920.	Much fainter than either of its neighbors: perhaps half as bright as 12.
14	4861.6	Probably F: very wide: not less than 6 tenth-metres in width: measures made on center.
16	4352.	$H\gamma$? Wide, and difficult to see: but not doubtful.

It is not an easy matter to describe the intensities of these lines except by comparison with their immediate neighbors. As seen with a single prism attached to the 12-inch, the lines 11, 12, and 14 appear intermediate in brilliancy between the two green lines in the Wolf-Rayet star, Lalande 13412: the continuous part of the spectrum is, however, much brighter than that of the Lalande star.

The ordinates of the light curve, given above, are for the prism, although plotted to a normal scale: that is, the relative values of the *ordinates* are approximately correct, but the relative *areas* of different portions do not represent the relative amounts of light which these portions give. The curve was drawn at the eye end of the telescope.

The new star thus falls, apparently, into Vogel's class, II. *b*, bright lines being superposed upon an absorption spectrum.

It might be called a typical specimen but for the fact that the absorption appears to take the form of bands rather than lines.

Photographs may show, however, that these bands, such as those indicated in the curve between lines 11, 12, 13, and 14, are really made up of lines which have not been seen, by the writer at least, on account of the faintness (fifth magnitude) of the star.

Perhaps the general appearance of the spectrum cannot be better described than by saying that it has "a ragged look."

LICK OBSERVATORY,
18th of February, 1892.

ATTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects properly included in ASTRO-PHYSICS should be addressed to George E. Hale, Kenwood Astro-Physical Observatory, Chicago, U. S. A. Authors of papers are requested to refer to page 256 for information in regard to illustrations, reprint copies, etc.

A New Star in Auriga.—A telegram received from Professor E. C. Pickering of the Harvard College Observatory gives the following position for a new star in Auriga: R. A. $5^h\ 25^m\ 33^s$, Decl. 30° 22′ 14″. On Feb. 15 the star was of the fifth magnitude. We learn from Professor Holden that all the resources of the Lick Observatory have been brought into play in a study of the Nova. Photographs are being taken with the 36-inch telescope for position, and with the Crocker telescope (several times each night) for magnitude; Polaris is used as a standard on the plates for photometric determinations. The spectrum is also being observed for relative brightness of lines, and measures of their position will follow. At the Kenwood Observatory cloudy weather has up to the present time prevented any observation.

The note below from *Nature* February 4, tells of the first observations of the *Nova:* The following circular was issued from the Royal Observatory, Edinburgh, 1892, February 2:

Yesterday an anonymous post-card was received here bearing the following communication:

"*Nova* in Auriga. In Milky Way, about two degrees south of χ Aurigæ, preceding 26 Aurigæ. Fifth magnitude, slightly brighter than χ."

At $6^h\ 8^m$ G. M. T. the star was easily found with an opera glass. It was of a yellow tint, and of the sixth magnitude, being equal to 26 Aurigæ. Examined with a prism between the eye and the eye-piece of the 24-inch reflector, it was immediately seen to possess a spectrum very like that of the Nova of 1866. The C line was intensely bright, a yellow line about D fairly visible; four bright lines or bands were conspicuous in the green; and lastly a bright line in the violet (probably Hγ) was easily seen.

A telegraphic notice was sent to Greenwich in the afternoon, and later on,

when the true nature of the object was recognized, to Kiel, for general distribution. The star was photographed last night at Greenwich.

Its place for 1892.0 is $5^h\ 25^m\ 3^s + 30°\ 21'$. It does not occur in the Bonn map. RALPH COPELAND.

Dr. Huggins has sent us the following note on his observations of the spectrum of the Nova; it was first printed in the *London Times*, Feb. 8, 1892:

"Our observations began on the evening of the 2nd inst., when the star was not much brighter than the 5th magnitude, less bright than the star of 1866, which was about the 2nd magnitude, and that of 1876, which was about 3½ magnitude when first observed.

"The most noticeable feature in the new star's spectrum—common also to the stars of 1866 and 1876—and which Dr. Copeland had already seen, was the very great brilliancy of the red, green, and blue lines of hydrogen. The reality of these lines was made certain by comparison with the corresponding lines of terrestrial hydrogen. The bright double line of sodium was conspicuous and its nature confirmed by a comparison with a flame containing sodium. Very striking were three brilliant lines in the green on the red side of F, and making with it a remarkably splendid quartet of bright lines. The first line is distant from F about one-third of the interval separating it from the second line. The next line falls, as was shown by the method of direct comparison, very near the position of the chief nebular line. But it is not possible to say certainly yet whether it is the nebular line or a line of some other substance accidentally close to it. It is desirable that the motion in the line of sight of the star should be known, in consequence of which the whole spectrum might be shifted a little towards the red or the blue. The cloudy state of the sky on Friday night prevented us from attempting the determination of the star's motion. The probability of the presence of the chief nebular line would be much greater if the second nebular line were found in the star, and there are, indeed, three lines, but much fainter relatively, not far from the position of the second line. At present we reserve our opinion, though we incline to consider no one of them to be the second nebular line. The third brilliant line from F appears in a small spectroscope to fall near the beginning of the brightest of the hydro-carbon flutings, but greater resolving power shows the line or band not to be coincident with this fluting.

"The spectrum of the star is superb, glittering with lines throughout. There are bright lines in the red near C; a brilliant line about one third of the distance from C to D; and there is a bright line on each side of D.

"If only the weather be propitious, we hope to clear up the points I have mentioned, as well as many others, and to supplement our eye observations by photographs of the invisible region of the spectrum."

We learn from *Nature* of Feb. 11 that the spectrum of the Nova was photographed at South Kensington by Mr. Norman Lockyer on the night of Feb. 3, employing a 6-inch objective with a prism before it. The approximate positions of 13 lines were obtained from two photographs, and *G*, h, H, and K were present. No mention is made, however, of the remarkable characteristics of the spectrum which are so well brought out in Professor Pickering's photograph. The visual spectrum was examined with a 3-foot reflector, and of it Mr. Lockyer remarks: "C was the brightest line observed. In the green there were several lines, the brightest of which was in all probability F, the position being estimated by comparison with the flame of a wax taper. Another line was coincident—with the dispersion employed—with the radiation at wave-length 500 from burning magnesium wire. A fainter line between the two last named was probably

near λ 495, thus completing the trio of lines which is characteristic of the spectra of nebulae. There was also a fairly bright line or band coincident with the edge of the carbon fluting at λ 517 given by the flame of the taper. A feeble line in the yellow was coincident under the conditions employed with the sodium line at D. The hydrogen line at *G* was distinctly seen, as well as a band or group of lines, between G and F."

Nova Aurigæ.—Letter from Professor Holden.

LICK OBSERVATORY, February 18, 1892.

MY DEAR MR. HALE:

Dr. Crew will send you to-day or to-morrow a short note on the visible spectrum of Nova Aurigæ. Besides the observations which he gives, others have been made here, which will be published in due time. They are

(*a*). A series of visual comparisons of the magnitude of the new star with the magnitudes of H. P. 1001 and 1033 by Professors Schæberle and Campbell.

(*b*). A series of photographs of the neighborhood of Nova and of Polaris (with the Crocker portrait-lens on the same plates) for the purpose of determining the photographic magnitude of the new star. At least one such plate has been taken by Professor Schæberle, and at once developed, on every clear night since the afternoon of February 6 (when we first heard of the star's appearance). Whenever desirable (and possible) other plates have been taken on the same nights. A considerable range of variation in magnitude has been manifested in the observations already made, and they appear to fall into a short period. Further good weather is required to decide this point.

(*c*). Visual spectroscopic observations have been made by Professor Campbell on several nights. The places of some 25 bands and lines have been fixed by measurements. Comparisons show that the hydrogen lines are bright and that D (not D^3) is also bright.

(*d*). The spectrum has also been photographed by Professor Campbell with the 36-inch and the 12-incn equatorials. The photographs fix the place of some 25 other bands and lines in the spectrum; and they confirm his visual observations with regard to the nature of the hydrogen lines of the star. Attempts to photograph the D's were not successful, as our plates were not suitable.

Other series of observations are planned and will be carried out if the weather permits. I am, my dear Mr. Hale,

Very sincerely yours,

EDWARD S. HOLDEN.

Progress in Solar Photography at the Kenwood Observatory.—In the last number of ASTRONOMY AND ASTRO-PHYSICS it was stated in a "Note on Recent Solar Investigations" that photographs had been obtained at the Kenwood Observatory of the regions on the Sun in which the H and K lines are reversed. Since that time the work has been continued, and it has been found that the reversals take place in the faculæ, so that we are now in possession of a new method of photographing the faculæ. The great advantage which this method offers lies in the fact that the faculæ are as well shown at the center of the Sun's disc as at the limb. We shall thus be able to study them more thoroughly than has before been possible. The spots are shown on the same plates with the faculae, and with a somewhat slower speed of the clepsydra the prominences are obtained by the same method. Since the great spot entered the disc on Feb. 4 we have obtained 45 photographs showing the spot and surrounding faculae, and a large number of its spectrum.

The first photographs showing all the prominences around the Sun's limb with a single exposure were made here early in February.

Group of Stars of the Fifth Type in Cepheus.—Professor E. C. Pickering communicates to *A. N.* 3070 the following note on this subject: "The photographic spectra of the stars DM. + 55°.2721, magn. 8.9, and DM. + 56°.2818, magn. 8.9, whose approximate positions for 1900 are in R.A. $22^h\ 15^m$; Dec. + 55° 37′, and R.A. $22^h\ 32^m.9$; Dec. + 56° 23′, are well shown in a photograph taken at the Harvard College Observatory on October 10, 1891. They prove to be of the fifth type, their spectrum being similar to that of the stars discovered by Wolf and Rayet. On November 2, 1891, a photograph of the same region was taken for confirmation of this peculiarity, and from this plate another star having a spec-

trum of the fifth type was discovered. The approximate position of this star for 1900 is in R.A. $22^h\ 23^m.7$; Dec. $+ 55°\ 46'$. The presence of bright lines in the spectrum of the last named star was confirmed from a plate taken on November 3, 1891. This increases the number of known fifth type stars to 38. These three stars, like all the others of the same class, fall near the central line of the Milky Way, their galactic latitudes being $- 0°\ 50'$, $- 1°\ 25'$ and $- 1°\ 20'$ respectively. Their galactic longitudes are $70°\ 29'$, $73°\ 3'$ and $71°\ 38'$ respectively."

Nebulosity about the Wolf-Rayet Stars.—In the January number of *Knowledge* there is an interesting letter from Rev. T. E. Espin in regard to Dr. Max Wolf's photographs of Cygnus. In spite of the bright illumination of the sky by a moon only three days past the full, the Rev. Espin was able to see every star shown in Dr. Wolf's beautiful photograph (reproduced in *Knowledge*, December 1891), in the three zones which he examined. It is thus regarded as probable that all the stars on the photograph, which was given an exposure of thirteen hours, are within the 14.5 magnitude on Argelander's scale.

But another fact is brought out which is very significant. It will be remembered that in Dr. Huggins' paper on the spectrum of the Wolf-Rayet stars in Cygnus (Proceedings Royal Society, No. 296) an account is given of some photographs taken by Mr. Isaac Roberts to ascertain whether any nebulosity were present in connection with these peculiar bright line stars. With an exposure of $3^h\ 15^m$ Mr. Roberts found no traces of nebulosity. But recent results show that this negative conclusion was probably due to the too great focal length of the telescope employed. At the request of the Rev. Espin, Dr. Wolf has photographed the same region with his short focus portrait lens, and although the exposure was too short to bring out any definite form, there seems to be no doubt that the Wolf-Rayet stars, and also the bright line star P Cygni, are directly connected with nebulous matter. Considering the peculiar type of spectrum which these stars possess, and the fact that they tend to group themselves in the plane of the Milky Way, this discovery of nebulous appendages must be regarded as of considerable importance.

Photographic Halation and Its Remedy.—The reflection of light from the back of the plate during exposure is often very troublesome in astronomical photography, and many methods of obviating the difficulty have been proposed. In the *Photographic Times* for Feb. 5, 1892, a method which was devised by the well-known spectroscopist, M. A. Cornu, is described as follows: "If we make a mixture of *six volumes of essence of clove and one volume of turpentine oil* we find that it possesses the same index of refraction as glass by immersing in it a strip of glass plate from which the emulsion has been scraped off. In the liquid the plate is almost entirely invisible, the edges only being apparent by a slight red or bluish green coloration. The mixture is thickened with lampblack to form a paste, which is applied on the back of the plate with a brush or a tuft of cotton. The photo film is exposed in the camera, and, before developing, one wipes off the black paste, and then develops as usual. These manipulations are not very agreeable, but it gives one the absolute certainty that the halo will be entirely avoided."

In the *Year Book of Photography* for 1886, Mr. Edgar Clifton recommends a mixture of burnt sienna ground in water with dextrine and water until the consistency of thick cream is reached. This is applied to the back of the plates with a soft sponge, and will be dry and ready for use in from fifteen to twenty minutes.

XUM

A dyed collodion film in contact with the back surface of the plate has also been proposed, but one of the above methods would probably prove more satisfactory.

Herr Schumann's New Vacuum-Spectrograph.—In a letter dated Jan. 15 Herr Schumann writes us from Leipzig that by diligent work during the holidays he has been able to practically complete his new spectrograph, which is to be used in a vacuum for photographing the extreme ultra-violet of the hydrogen spectrum. Reference was made to this instrument in our note in the February number on Herr Schumann's discoveries, where it was pointed out that the shortest light-waves are absorbed by air, and must therefore be investigated in a vacuum.

The spectrograph is furnished with a 70° prism and two lenses of 120^{mm} focal length (for λ 5890). The material of which they are made is white fluor-spar, obtained for Herr Schumann in a remarkably pure state by the well-known optical house of Carl Zeiss. Quartz cannot be used in this research, as it exercises considerable absorption above λ 1820. In its present improved form the spectrograph is so constructed that all of the following adjustments can be made when the instrument is in a vacuum, or filled with any gas at a pressure up to one atmosphere:

1. The width and length of the slit may be changed and measured micrometrically.
2. A diaphram of adjustable length may be moved by a micrometer screw over the slit, so as to allow a large number of spectra to be taken on a single plate for comparison.
3. The lenses of collimator and camera may be moved in either direction for focusing.
4. The tubes of both collimator and camera may be turned in such a way that the angle between their optical axes varies about 30°.
5. The prism may be set for minimum deviation.
6. The sensitive plate may be turned about its central line so as to make any angle from 0° to 90° with the optical axis of the camera lens.
7. The photographic plate may also be moved in its own plane in a direction parallel to the slit, so as to give space for several series of exposures.

The spectrograph is exhausted by a Geissler mercury-pump. It has already been tested satisfactorily, and we may shortly expect to hear of important results obtained by its means.

The Aurora of Feb. 13, 1892.—Auroras can rarely be seen from the Kenwood Observatory, owing to the illumination of the northern sky by the lights of Chicago, but the magnificent display of February 13 was easily observed. At about 6^h 25^m P. M. (Chicago M. T.) the brilliant red auroral light was first seen here, extending more than two-thirds the distance from the horizon to the zenith, and reaching about 45° east and west of north. Local changes in brilliancy and depth of color were very rapid, and straight, white streamers partook of the general motion from east to west. At about 6^h 55^m the aurora disappeared.

The spectrum was well seen here with a small direct-vision spectroscope, using a rather wide slit. Four bands were made out, and their positions were estimated as follows:

1. Bright; probably same width as slit; in red near C.
2. Bright; probably same width as slit; yellowish green ("aurora line?")
3. Very faint; broad and hazy; in green, near *b*.
4. Faint; probably same width as slit; near F.

The appearance of the electric storm which accompanied the aurora was first noticed on Feb. 13, about 1 P. M. Between 5 P. M. and 7 P. M. the storm was at its height, and interfered with the working of the telegraph system over a considerable section of the country. At intervals during the auroral display it was found possible to send messages between Albany and New York without the aid of the regular batteries. (*Chicago Tribune*).

The question naturally arises whether these phenomena were in any way connected with solar disturbances. The regular observations of the Sun were in progress during the greater part of the day at the Kenwood Observatory, but no very remarkable outbreaks were observed. At noon, there were evidences of activity in the region of the great spot group, and the distortions of the hydrogen C line indicated a greater velocity (downrush) than has been noticed before in this group. A bright prominence on the N. E. limb, following the small spots which were already well advanced on to the disc, showed in the C line a marked distortion toward the violet, and at $4^h\ 10^m$ this had considerably increased in amount. 14 photographs of prominences, spots and faculae, and 11 of spot and prominence spectra, were made here between $10^h\ 30^m$ A. M. and $4^h\ 15^m$ P. M.

We wish to call attention, in this connection, to the work of Dr. M. A. Veeder, of Lyons, N. Y., on the relation between auroras and solar phenomena. As has been mentioned before in ASTRONOMY AND ASTRO-PHYSICS, Dr. Veeder has prepared blank forms to be filled out with notes on auroras, and these he is glad to furnish to anyone who is willing to spend a few minutes each evening on the work. In another Note we print a report we have received from him on the auroras of January. It is to be hoped that many will be ready to offer their assistance in this interesting investigation.

Newspaper dispatches received later show that the aurora was very widely seen. In Sweden and Russia, earth currents seriously affected the operation of the telegraph lines.

The following is Dr. Veeder's report of the aurora of Feb. 13, as observed at Lyons, N. Y.

Description, Strong scarlet red streamers marking the central portion of the region in which this feature was prominent and persistent throughout the continuance of the display, or in other words, from 6.45 P. M. until 8.06. (Eastern Standard Time).

Time, Special observations were made at 6.59, 7.03, 7.07, and 7.09 P. M.

Azimuth at point of origin, 50° W. of N.

Inclination, Westward at an angle with the horizon of 80°.

Altitude, Varied from 45° to 50°.

Description, Bright red streamers forming the detachment from the preceding which extended farthest south of any seen during the evening.

Time, 7.55 P. M.

Azimuth of origin on horizon, 65° W. of N.

Inclination, Westward at an angle of 78°.

Altitude, 35°.

Description, Faint yellowish green streamers which varied in brightness in sympathy with those described in the following section, but which had the peculiarity of not conforming to the usual lines of magnetic force.

Time, 11.58 P. M.

Azimuth of point of origin on the horizon, 12° E. of N.

Inclination, Westward at an angle of 55°.

Altitude, 35°.

Description, Yellowish green streamers entirely similar to the preceding, but conforming to the more usual direction.

Time, 11.59 P. M.

Azimuth of origin, 19° E. of N.

Inclination, Eastward at an angle with the horizon of 87°.

Altitude, 40°.

Prominent features were noted during the evening as follows:

The time of beginning was almost precisely 6.40 P. M. At that moment a small patch of greenish streamers was seen about 15° above the horizon at a point due N. E. At 6.45 a rosy blush was observed in the N. W. in the location of the prominent and persistent streamers above described. At 6.52 a curtain having a sinuous lower margin from which short green streamers arose vertically formed just below the North Star. At 6.56 a faint and irregular streak of luminous haze extended E. and W. through the zenith. At 6.59 red streamers began to form in the N. W. and continued to brighten at 7.03, becoming very strong at 7.07. At this moment faint red patches began for the first to appear in the N. E., in which location greenish patches and streamers only had appeared hitherto. Generally the display was less bright east of the meridian, and the colors were mostly of some hue of green or light yellow, but west of the meridian red was the predominating color throughout, and the streamers were much stronger and more persistent. At 7.08 an irregular band made up of patches and streamers extended E. and W. across the sky about 20° N. of the zenith. The color of this band was generally red, but nearer the horizon, particularly toward the N. E., the colors were at this moment greenish. At this moment also the maximum extent of sky covered was attained, the display extending very nearly to the zenith. Generally throughout the evening the southern margin of the luminous mass did not extend further S. than the North Star, but remained persistently at about that point. At 8.05 the aurora was fading rapidly, and at 8.06 had disappeared entirely. At 8.15 a faint red glow appeared for a few minutes about 20° above the northern horizon. At intervals later in the evening very faint haze was seen overspreading the sky, from the zenith northward, which might have been auroral in character. At 11.45 a small patch of bright green streamers was seen in the N. E., at almost the precise location where the display began at 6.40. At 11.58 and 11.59 the streamers above described as being seen at that hour were first noticed, but faded out in about three minutes.

The Auroras of January, 1892. The following results appear to be justified by the reports of observations thus far received. As was anticipated and announced in advance to many of those receiving blanks for recording observations, the finest display of the month, and an aurora of the first magnitude, appeared on January 5th. Sporadic, and for the most part very faint displays were reported on January 15th, 20th, 21st, 25th, 26th, 27th, 28th and 29th, those on the last three dates named being the best defined.

The reports from stations along the base line adopted, extending from Washington northward into Canada, show that the aurora of January 5th had a probable altitude of 175 miles and perhaps upwards. The amount of sky covered at different stations shows that the plane of the southern margin of the chief portion of the luminous mass reached the earth at a point on the 77th meridian not far from 45° north latitude. Comparison with observations on other meridians shows that the aurora tended to reach its maximum brightness at the same hours of local time, rather than at the same hours of absolute time. A study of

the arrangement of the arches and patches of light reported from different stations reveals the fact that they are very largely of the nature of halos, their position depending as much upon the position of the observer as upon the general source of illumination in the auroral mass. As in the case of a rainbow, each observer sees his own arch and consequently the elevation will be approximately the same at stations not too far apart to prevent the arch from being seen at all. In this way, also, the differences in the prismatic colors displayed, even at stations quite close together, may be accounted for. Hence the difficulty of employing arches or colors for the estimation of altitude. It is suspected that this may be true of streamers also.

The method of recording the absence as well as the presence of the aurora at each observation has made it apparent, especially in connection with the lesser displays of the month, that even well defined auroras may be confined within quite narrow limits, appearing, for example, at southern stations when absent at those directly northward. The aurora thus exhibits a tendency to frequent certain localities, presumably because of some peculiarity of the soil or topography of the country; but further observations in regard to this point are desirable.

Disturbed areas upon the Sun, containing both spots and faculae, appeared by rotation on January 5th, 6th, 15th, 21st, 28th, 29th and 30th. Thus the dates of auroral display during the month, and the extent of the displays reported, has been in exact conformity with the relations to solar and associated conditions described in the paper upon the Zodiacal Light, copies of which have been distributed generally to observers co-operating, and which may be obtained from the undersigned, from whom, also, blanks and circulars for auroral observations may be had.

M. A. VEEDER,

LYONS, NEW YORK, U. S. A.,
February 8, 1892.

The Eruptive Prominence of July 9, 1891.—In the January number of ASTRONOMY AND ASTRO-PHYSICS an account was given in an article on "Recent Results in Solar Prominence Photography" of a prominence observed simultaneously at the Haynald Observatory, Kalocsa, Hungary, and at the Kenwood Observatory, Chicago. We have recently received a letter from Mr. J. Evershed, Jr., of Kenley, Surrey, England, in which he writes as follows:

"I take the liberty of writing you, thinking you may be interested to learn that the prominence of July 9th last, photographed by you and observed at the same time at Kalocsa, was also, by an extraordinary chance, well seen by me here. I am very rarely at liberty to observe in the afternoon, but happened to be so on the above date; furthermore, the Sun is hidden in trees from about 4 P. M. to sunset, but there is a gap in the foliage which allows it to be seen for about 20 minutes between 5:30 and 6 P. M., and it was during this time my observation was made. I enclose copies of my drawings made at the time. My observation of the form of this prominence differs somewhat from M. Fényi's drawing in that the main stem seemed to me much narrower, and not so inclined. I first observed the N. F. limb at 5.30 $\pm$ 2^m G. M. T., at which time the brilliant column had a 'stranded' appearance like a partly unravelled rope. Near the highest part a number of bright filaments like descending rockets gave the impression of matter falling back on the Sun, but these faded very rapidly, and before any actual motion could be detected. With a narrow slit C was much distended on each side of its normal position near the base of the column.

"I may mention in connection with photographic work that I have been lately experimenting on the F hydrogen line with a view to photographing the

prominences. I find with an exposure of a little over 1 second with rapid isochromatic plates a very distinct impression can be obtained of the ordinary quiet prominences, but of course less detail is visible than in visual observation with C. I therefore conclude that for simply registering the forms F is a more promising line than K, which I understand requires a more prolonged exposure in spite of the dark background due to the broad absorption shade."

We were much interested to learn of Mr. Evershed's observation; there certainly was a remarkable series of coincidences connected with the eruption referred to. It lasted but 20 minutes, and was seen in Hungary, England and the United States. Clouds in Kalocsa and trees in Kenley nearly succeeded in preventing observation, but the view of the Sun was unobstructed at exactly the right time. The drawings which Mr. Evershed kindly sends agree with M. Fényi's and our own execpt in the inclination to the limb, as has been mentioned.

As to the F line, we are inclined to doubt whether it will prove as useful for prominence photography as K, although the use of dyes may give plates a greater sensitiveness for this region. Our ordinary time of exposure in the last experiments with an open slit was about ½ second for K and the broad dark shade is an advantage of the greatest importance. F was used in some of our earlier experiments, and, though not considered so useful as K, a careful comparative test should be made, in order to settle the matter.

The Spectra of Sun-Spots and the Photosphere. In his important memoir, "Recherches sur la Rotation du Soleil," Professor N. C. Dunér not only gives a most complete discussion of his investigations on the rotation of the Sun, but also adds a description of the large and powerful diffraction spectroscope employed, together with some results obtained with this instrument in an examination of the Sun-spots and photosphere. The large size and special construction of the spectroscope makes its description particularly interesting, and as soon as we can procure a suitable photograph or drawing, a translation of Professor Dunér's account will appear as one of our series on *The Modern Spectroscope*. At present, we wish only to call attention to some of the results secured.

Adopting the wave-lengths of M. Fievez, Professor Dunér first gives a list of double lines which lie just within the resolving power of his instrument, and certainly the claim of rare optical qualities for the spectroscope is completely justified by the extreme closeness of some of these pairs. In speaking of the duplicity of the two D lines it is stated that a narrow thread of light may be seen without great difficulty in the center of D_2, and sometimes, though rarely, in D_1, when the fourth order spectrum is employed. In the fifth order the same appearance is much more easily recognized. The author goes on to add: "As to this fine line of light, I am almost convinced that it is only a double reversal, similar to those so often observed in the spectra of spots and prominences, and which would be seen over the entire disc of the Sun with a sufficiently powerful spectroscope. I have noticed another very curious phenomenon in the b group: a very considerable decrease in the intensity of the three wide lines which belong to magnesium. In the fifth spectrum this decrease of intensity is so marked that the more refrangible component of b_4 is only recognizable with some difficulty,—with more difficulty, in fact, than in the fourth spectrum; while the less refrangible component of b_4, as well as the two components of b_3, which are due to nickle and iron, retain all their sharpness. As is well known, b_2 is enclosed between two metallic lines. With a considerable, though not too great, dispersion b_2 is seen to be much stronger than even the more refrangible of these lines; but in the fifth spectrum of

our spectroscope b_2 is sensibly fainter than the less refrangible of the lines. b_1 is also seen to be very much reduced in intensity. It would seem that these phenomena might be explained by a partial reversal, while the lines of the more refractory metals do not undergo a similar change. One objection might, however, be raised against such a supposition: the line of the solar corona (K 1474) which presents elsewhere, in general, the same reversal phenomena as the magnesium lines, is not in the least enfeebled in the spectrum of the fifth order."

The discovery recently made at the Kenwood Observatory, and noted in our last number, that the H and K lines are reversed in regions irregularly distributed over the entire disc of the Sun, should be considered in connection with Professor Dunér's observations. In the photographs of H and K, however, though there is some reason to think that the lines are reversed throughout their entire length, the reversals can be certainly seen only at intervals along the lines, while Professor Dunér's account gives the impression that a continuous reversal was seen in the lines of the *b* group. In the case of D_3 it seems that the reversal was not continuous, for it is remarked that with a sufficiently powerful spectroscope, it would probably be seen over the whole disc. As it has been found here that the regions in which H and K are most strongly reversed correspond with the faculae, it is likely that the reversals of magnesium and sodium occur in the same localities. Considering the relative frequency with which these various lines are reversed in prominences, it is not at all surprising, but rather to be expected, that in the faculae they should follow the same order. Thus hydrogen and calcium are always found to be bright, while magnesium and sodium appear so with much greater difficulty.

Professor Dunér found no difficulty in confirming Professor Young's resolution of the dark shade in the spectrum of a spot nucleus into a great number of fine lines. He remarks: "I have, in fact, seen spot-spectra entirely lose the appearance of a uniform band, darker than the rest of the solar spectrum, which they present in a spectroscope of medium dispersion, and showing very numerous dark lines, projected on a background of the same brilliancy as the general spectrum of the solar disc. These lines are *not* uniformly distributed, however, and at equal distances from one another like the bars of a grate. On the contrary it may be seen with perfect certainty, especially when attention is directed to the spaces which in the solar spectrum are free from all but faint lines—I mention as examples the open spaces 5352 . . . 5361, and 5287.5 . . . 5292—that they are grouped in doublets, triplets, etc., separated by interstices wider than those which separate the lines constituting these groups. All of these interstices, as far as I could determine, seemed to me to be of the same brilliancy as those which occur between groups of lines in the solar spectrum. By very carefully examining the solar spectrum in the prolongation of such a group in the spot spectrum I sometimes succeeded in discovering an exceedingly faint nebulous line. In a word, all that I have seen seems to me to prove that there is no fundamental difference between the general solar spectrum and that of the spots. It is, on the contrary, very probable that the latter is formed, so to speak, by the exaggeration of the essential characteristics of the former, the excessively feeble and almost imperceptible lines becoming readily visible, and the lines which are strong in the ordinary solar spectrum becoming broadened and strengthened.

The absorbing layer in the spots having, with slight modifications, the same chemical composition as that of the photosphere, it is difficult to imagine any other kind of spot than that of a cavity filled with metallic vapors, either in vortices as M. Faye maintains, or at rest as Secchi believed, although the con-

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stancy of the lines which properly belong to spot spectra, as determined by Professor Young and myself, seems more in accord with Secchi's theory. But it can hardly be admitted that the spots are of the nature of a cloud floating in the solar atmosphere. For clouds as we know them in the terrestrial atmosphere are partly fluid and partly gaseous, and they are, consequently, but slightly transparent. It would thus be necessary that the solar clouds should have a spectrum showing general absorption. A spectrum composed of numerous dark lines on a bright background could not be explained on this hypothesis. Professor Young has also expressed the same opinion, in the note just mentioned (*American Journal of Science*, Third Series, vol. XXV, pp. 333-336). He remarks: 'Of course the resolution of the spot spectrum into lines tends to indicate that the absorption which darkens the center of a Sun-spot is produced, not by granules of solid or liquid matter, but by matter in the gaseous form.' "

We may add that the fine lines in the spectrum of the spot nucleus have been frequently observed at the Kenwood Observatory, the appearance agreeing in all respects with that described above. In stating his belief that there is no fundamental difference between the spot spectrum and that of the general solar surface, we do not understand Professor Dunér to mean that the relative intensities of the lines is invariable, for of course, in spot spectra, some of the solar lines are very much more widened than others. What brings about this selective absorption, and why it varies from one spot to another, and also, probably, with the Sun-spot period, are some of the most interesting questions of solar physics.

CURRENT CELESTIAL PHENOMENA.

PLANET NOTES FOR APRIL.

Mercury will be visible to the naked eye, a little after sunset, in the first few days of April. He will then be in the constellation Aries, south of the brightest star. Mercury, however, will be brighter than the star, so that no doubt will exist as to the identification of the planet. One should look for Mercury about half an hour after sunset, almost due west and a short distance above the horizon. After the first few days of the month Mercury will move rapidly toward the west, coming to inferior conjunction with the Sun, April 19.

Venus cannot fail to catch the eye of the most unobservant in the early evening, as she is the most brilliant object in the sky with the exception of the Moon. Even during the day she can easily be seen without a telescope, if one knows just where to look. During April her brilliancy will be fifty per cent greater than now. The phase will be gibbous up to the last day of April, when almost exactly half of the disk will be illuminated. The diameter will increase during the month from 18″ to 24″. April 29, about 11 P. M. central time, there will be an occultation of Venus by the moon. It will be visible in Mexico, the west coast of South America, and some of the Islands of the Pacific ocean.

Mars during April will rise between one and two o'clock in the morning. He is in Sagittarius moving eastward. His brilliancy and red color will enable anyone to distinguish him from the stars of the constellation.

Jupiter rises too late in the morning to be well seen.

Saturn is now a beautiful object in the telescope. The rings are so nearly edgewise to us that they appear as one, but the belts and the shadow of the rings

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on the planet show well. For chart of Saturn's place in the constellation Virgo, see our January number, p. 81.

Uranus is also in Virgo (see chart, January No., p. 81) near the star λ. Uranus will be at opposition April 23, so that this month will be most favorable for observations of this planet. We would call especial attention to the occultation of Uranus by the Moon April 12, beginning, as seen from Washington, at $10^h\ 56^m$ P. M., and ending at $12^h\ 22^m$ A. M. central time. For other places the times of immersion and emersion will vary by several minutes, so that it will be well for the observer who wishes to observe these phenomena to begin watching a half hour or more early.

Neptune will set too early during April to be observed under favorable conditions.

MERCURY.

Date 1892.	R. A. h m	Decl. ° ′	Rises. h m	Transits. h m	Sets. h m
Apr. 5.....	2 01.9	+15 43	5 56 A. M.	1 03.7 P. M.	8 11 P. M.
15.....	1 57.9	+14 38	5 17 "	12 20.4 "	7 23 "
25.....	1 37.0	+ 9 58	4 41 "	11 20.3 A. M.	7 00 "

VENUS.

Apr. 5.....	3 50.8	+22 32	7 12 A. M.	2 52.3 P. M.	10 32 P. M.
15.....	4 36.8	+24 58	7 06 "	2 58.8 "	10 52 "
25.....	5 22.1	+26 26	7 04 "	3 04.6 "	11 06 "

MARS.

Apr. 5.	18 58.1	−23 23	1 37 A. M.	6 00.1 A. M.	10 24 A. M.
15.....	19 22.3	−23 00	1 20 "	5 45.8 "	10 10 "
25.....	19 45.4	−22 29	1 02 "	5 29.6 "	9 58 "

JUPITER.

Apr. 5.....	0 18.4	+ 0 48	5 15 A. M.	11 21.4 A. M.	5 28 P. M.
15.....	0 27.1	+ 1 44	4 41 "	10 50.8 "	5 01 "
25.....	0 35.7	+ 2 39	4 06 "	10 20.0 "	4 34 "

SATURN.

Apr. 5.....	11 46.5	+ 4 11	4 27 P. M.	10 46.7 A. M.	5 07 A. M.
15.....	11 41.1	+ 4 26	3 44 "	10 04.9 "	4 26 "
25.....	11 42.0	+ 4 38	3 02 "	9 23.6 P. M.	3 45 "

URANUS.

Apr. 5.....	14 10.7	−12 38	7 58 P. M.	1 10.6 P. M.	6 23 A. M.
15.....	14 09.2	−12 30	7 17 "	12 29.7 "	5 43 "
25.....	14 07.5	−12 21	6 35 "	11 48.7 "	5 02 "

NEPTUNE.

Apr. 5.....	4 21.5	+19 58	7 56 A. M.	3 23.0 P. M.	10 50 P. M.
15.....	4 22.7	+20 01	7 17 "	2 44.8 "	10 12 "
25.....	4 24.0	+20 04	6 39 "	2 06.8 "	9 35 "

THE SUN.

Apr. 5.....	1 00.5	+ 6 28	5 32 A. M.	12 02.5 P. M.	6 32 P. M.
15.....	1 37.2	+10 08	5 15 "	11 59.8 A. M.	6 45 "
25.....	2 14.6	+13 31	4 59 "	11 57.8 "	6 57 "

Phases and Aspects of the Moon.

		Central Time. h m
First Quarter	Apr. 4	12 21 A. M.
Apogee	" 11	5 24 P. M.
Full Moon	" 12	12 26 A. M.
Last Quarter	" 19	12 00 midn.
Perigee	" 26	3 12 A. M.
New Moon	" 26	3 46 P. M.

Mr. Marth's Ephemerides of the Satellites of Saturn.

[From *Monthly Notices*, Nov. 1891.]

In this table the times have been changed from Greenwich Mean Time to Central Standard Time. The abreviations *Rh.*, *Te.*, *Di.*, *En.*, and *Mi.*, stand for the names of the satellites Rhea, Tethys, Dione, Enceladus, and Mimas. The letters *a*, *b*, *c*, *d*, and *e*, stand for conjunctions of the satellites in order as follows: With the preceding end of the outer ring; with preceding end of planet's equatorial diameter; with center of planet; with following end of planet's diameter; with following end of ring. The letters *n* and *s* signify that the satellite at the time of conjunction is north or south of the point designated by the preceding letter; *Sh.* means that the shadow of a satellite is near the central meridian of the planet; *Ecl. D.* and *Ecl. R.*, the disappearance and reappearance of a satellite at beginning and end of an eclipse.

March 1892.		March 1892.		March 1892.		March 1892.	
5 12.3 am	Di en	4.7	Mi an	17 12.1 am	Di es	23 12.7 am	En an
12.9	Te Ecl. D	4.8	En an	12.8	Rh an	2.2	Te bs
1.0	Mi an	4.9	Te Ecl. D	1.6	Mi as	3.9 pm	Mi as
4.0	Te dn	7.8	Te dn	2.3	Di ds	5.2	En es
3.7 pm	En en	9.8	Te en	3.1	En as	7.3	Rh es
6.0	Rh es	10.6	Mi en	3.4	Rh bn	8.0	Te an
6.2	Mi as	11.2	En en	12.4 pm	Te as	8.2	Di an
8.6	Rh ds	11 12.8	Di es	12.9	Mi en	9.3	Mi an
9.7	Te es	1.6	Te es	1.2	En an	9.9	Rh ds
9.8	En es	2.3	Titan ds	6.3	Mi es	10.0	Te bn
11.6	Mi an	3.0	Di ds	7.6	En en	10.4	Di bn
11.7	Te ds	3.3	Mi an	18 12.2 am	Mi as	11.5	En as
6 12.4 am	Rh bs	3.6	Te ds	4.1	Te an	24 12.9 am	Te Ecl. R
1.5	Di es	3.6	En as	2.3 pm	Di Ecl. D	1.7	Rh bs
2.6	Te bs	4.6	Titan Sh	2.4	Di dn	1.7	Di Ecl. R
3.0	Rh bs	6.3	Di bs	4.6	Di en	2.9	Te en
3.7	Di ds	6.5	Te bs	4.9	Mi es	3.2	Mi en
4.1	En as	8.2	Titan bs	10.1	En an	3.9	Di en
4.6	Te as	8.5	Di as	10.8	Mi as	4.3	Rh as
2.2 pm	En an	8.5	Te as	19 2.7 am	Te es	2.5 pm	Mi as
4.8	Mi as	9.2	Mi en	1.4 pm	Rh bs	4.0	En en
8.3	Te an	12 12.0 am	Titan as	2.5	En es	6.6	Te es
8.6	En en	1.7	En an	3.5	Mi es	7.9	Mi an
10.2	Te Ecl. D	2.6	Mi es	4.0	Rh as	8.6	Te ds
10.2	Mi an	12.2 pm	Te an	4.1	Titan an	11.5	Te bs
7 1.2 am	Te dn	12.5	Rh an	5.7	Di es	25 1.5 am	Te as
3.2	Te en	1.9	Mi an	8.0	Di ds	1.8	Mi en
4.1	Mi en	2.2	Te Ecl. D	8.0	Titan bn	2.1	En es
12.4 pm	Di Ecl. D	3.0	Rh Ecl. D	8.9	En as	12.7 pm	Di as
1.0	En as	5.1	Te dn	9.4	Mi as	1.1	Mi as
3.4	Mi as	6.2	En es	11.2	Di bs	5.3	Te an
3.8	Di dn	6.9	Rh dn	20 1.4 am	Te an	6.5	En an
6.0	Di en	7.1	Te en	1.4	Di as	6.5	Mi an
7.0	Te es	7.8	Mi en	1.9	Titan dn	7.3	Te bn
8.8	Mi an	9.5	Rh en	2.8	Mi as	10.2	Te Ecl. R
9.0	Te ds	9.6	Di an	3.4	Te bn	26 12.2 am	Te en
11.1	En an	11.8	Di Ecl. D	5.7	Titan en	12.4	Mi en
11.9	Te bs	13 12.5 am	En as	1.3 pm	En en	12.8	En en
8 12.2 am	Rh an	1.2	Mi es	2.1	Mi es	1.5	Rh an
1.9	Te as	3.1	Di dn	8.9	Mi as	4.0	Rh bn
2.6	Rh Ecl. D	3.8 pm	Te bs	11.4	En es	1.9 pm	Di an
2.8	Mi en	4.9	En en	12.0	Te es	3.9	Te es
2.1 pm	Mi as	5.8	Te as	21 1.4 am	Mi an	4.1	Di bn
3.5	En es	14 2.1	Di as	2.0	Te ds	4.1	Mi an
5.6	Te an	2.4	Te dn	2.6	Di an	5.3	En as
7.1	Di es	4.4	Te en	4.8	Di bn	5.9	Te ds
7.5	Mi an	5.0	Mi en	4.9	Te bs	7.4	Di Ecl. R
7.6	Te Ecl. D	6.7	Rh es	1.1 pm	Rh an	8.8	Te as
9.3	Di ds	7.5	En an	3.7	Rh bn	9.6	Di en
9.9	En as	9.2	Rh ds	3.9	En an	10.8	Te as
10.5	Te dn	10.4	Mi es	6.7	Mi as	11.0	Mi en
9 12.5 am	Te en	15 1.1 am	Rh bs	7.5	Rh Ecl. R	27 3.4 am	En an
12.6	Di bs	1.8	En en	7.6	Rh dn	4.4	Mi es
1.4	Mi en	3.6	Rh as	10.1	Rh en	8.0	Titan es
2.8	Di as	1.1 pm	Te bs	10.2	En en	11.9	Titan ds
2.3 pm	En en	3.1	Te as	10.7	Te an	2.5 pm	Te an
4.3	Te es	3.3	Di an	22 12.1 am	Mi an	3.7	Mi an
6.1	Mi an	3.7	Mi en	12.7	Te bn	3.8	Titan Sh
6.3	Te ds	6.3	En as	3.6	Te Ecl. R	4.5	Te bn
9.2	Te bs	8.7	Di dn	1.6 pm	Di ds	5.7	Titan bs
11.2	Te as	9.1	Mi es	2.6	En as	7.5	Te Ecl. R
12.0	Mi en	11.0	Di en	4.9	Di bs	7.8	En es
10 12.4 am	En es	16 3.0 am	Mi as	5.3	Mi as	9.5	Te en
4.0	Di an	1.7 pm	Te en	7.1	Di as	9.5	Titan as
12.8 pm	Rh bs	2.3	Mi en	9.3	Te es	9.6	Mi en
2.9	Te an	7.7	Mi es	10.7	Mi an	10.7	Di es
3.3	Rh as	8.8	En es	11.3	Te ds	28 12.9 am	Di ds

March 1892.

	2.1	En as
	3.0	Mi es
	4.2	Di bs
	1.2 pm	Te es
	2.1	Rh bs
	2.3	Mi an
	3.2	Te ds
	4.6	Rh as
	6.1	Te bs
	6.6	En en
	8.1	Te as
	8.2	Mi en
29	1.6 am	Mi es
	1.1 pm	Di Ecl. R
	1.8	Te bn
	3.2	Di en
	4.8	Te Ecl. R
	6.7	Te en
	6.9	Mi en
	9.1	En an
30	12.3 am	Mi es
	3.5	En en
	12.5 pm	Te ds
	1.6	En es
	1.8	Rh an
	3.4	Te bs
	4.4 pm	Di es
	4.4	Rh bn
	5.4	Te as
	5.5	Mi en
	6.6	Di ds
	7.9	En as
	8.4	Rh Ecl. R
	9.8	Di bs
	10.8	Rh en
	11.9	Mi es
	12.0	Di as
31	2.2	Te Ecl. R
	4.6	Te en
	4.1	Mi en
	9.5	Mi es
	10.4	En es

April 1892

1	1.2 am	Di an
	3.4	Di bn
	3.4	Mi as
	2.7 pm	Te as
	2.7	Mi en
	2.9	En an

April 1892.

	8.0	Rh es
	8.1	Mi es
	9.2	En en
	10 5	Rh ds
2	2.0 am	Mi as
	2.4	Rh bs
	12.2 pm	Di ds
	1.3	Mi en
	1.3	Te en
	1.7	En as
	3.5	Di bs
	5.7	Di as
	6.7	Mi es
	11.8	En an
3	12.6 am	Mi as
	4.2 pm	En es
	5.3	Mi es
	6.8	Di an
	9.0	Di bn
	10.5	En as
	11.2	Mi as
4	12.5 am	Di Ecl. R
	2.1	Rh an
	2.5	Di en
	3.7	Te an
	1.7 pm	Titan an
	3.0	En en
	3.9	Mi es
	5.6	Titan bn
	9.9	Mi as
	(11.5	Titan dn)
	11.6	Titan Ecl. R
5	1.1 am	En es
	2.4	Te es
	3.3	Mi an
	3.4	Titan en
	3.7	Di es
	2.6 pm	Mi es
	5.5	En an
	8.5	Mi as
	11.9	En en
6	1.0 am	Te an
	1.9	Mi an
	3.0	Te bn
	2.7 pm	Di bn
	2.7	Rh bs
	4.3	En as
	5.3	Rh as
	6.2	Di Ecl R

April 1892.

	7.1	Mi as
	8.2	Di en
	11.7	Te es
7	12.5 am	Mi an
	1.7	Te ds
	5.7 pm	Mi as
	6.8	En es
	9.3	Di es
	10.3	Te an
	11.1	Mi an
	11.5	Di ds
8	12.3 am	Te bn
	1.2	En as
	2.8	Di bs
	3.4	Te Ecl. R
	2.5 pm	Rh an
	4.3	Mi as
	5.0	Rh bn
	5.6	En en
	9.0	Te es
	9.4	Rh Ecl. R
	9.7	Mi an
	11.0	Te ds
	11.5	Rh en
9	1.9 am	Te bs
	1.8 pm	Di en
	2.9	Mi as
	7.6	Te an
	8.2	En an
	8.3	Mi an
	9.6	Te bn
10	12.7 am	Te Ecl R.
	2.2	Mi en
	2.5	Te en
	2.5	En en
	3.0 pm	Di es
	5.2	Di ds
	6.2	Te es
	6.9	En as
	6.9	Mi an
	8.2	Te ds
	8.5	Di bs
	8.6	Rh es
	10.7	Di as
	11.2	Te bs
	11.2	Rh ds
11	12.9 am	Mi en
	1.2	Te as
	3.1	Rh bs

April 1892.

	4.9 pm	Te an
	5.6	Mi an
	6.9	Te bn
	9.5	En es
	10.0	Te Ecl R
	11.5	Mi en
	11 8	Di an
	11.8	Te en
12	2.0 am	Di bn
	5.7	Titan es
	9.5	Titan ds
	1.9 pm	En an
	3.0	Titan Sh
	3.3	Titan bs
	3.5	Te es
	4 2	Mi an
	5 5	Te ds
	7.2	Titan as
	8.3	En en
	8.5	Te bs
	10.1	Mi en
	10.5	Te as
13	2.8 am	Rh an
	2 1 pm	Di bs
	2.2	Te an
	2 8	Mi en
	4.2	Te bn
	4.3	Li as
	7.4	Te Ecl. R
	8.7	Mi en
	9.1	Te en
	10.8	En an
14	2.2	Te ds
	3 2	En es
	5.5	Di an
	5.7	Te bs
	7.3	Mi en
	7.7	Di bn
	7.7	Te as
	9 6	En as
	11.3	Di Ecl R
15	12.7 am	Mi es
	1.2	Di es
	3.4 pm	Rh bs
	4.7	Te Ecl. R
	5.9	Mi en
	6.0	Rh as
	6.4	Te en
	11.3	Mi es

Occultations of Stars by the Planets.

STARS NEAR VENUS.

Date		Central Time of Conjunction. h m		Diff. of Decl. ″	Maximum Duration. m	Magnitude of Star.
Apr.	1	8 16	P. M.	+ 70	6.7	9.4
	4	7 00	"	− 28	7.0	9.4
	10	11 18	A. M.	− 35	7.5	9.2
	11	9 53	"	+ 3	7.6	8.5
	11	10 03	"	+ 18	7.6	6.5
	27	2 27	P. M.	+ 43	9.4	9.3
	29	2 44	A. M.	− 53	9.6	9.0

STARS NEAR MARS.

Apr.	6	5 16	P. M.	+ 24	6.1	9.0
	9	3 23	A. M.	− 4	6.2	9.0
	17	1 39	P. M.	− 27	7.0	9.5
	20	9 27	"	+ 52	7.3	9.5
	22	6 46	A. M.	− 63	7.5	9.0
	23	12 54	A. M.	+ 21	7.5	9.5
	26	6 07	P. M.	+ 42	7.9	9.2

STARS NEAR SATURN.

Apr.	5	6 30	P. M.	+ 9	1.8h	9.3

Occultations Visible at Washington.

Date 1892.	Star's Name.	Magnitude.	IMMERSION Washington M. T. h m	IMMERSION Angle f'm N pt. °	EMERSION Washington M. T. h m	EMERSION Angle f'm N pt °	Duration. h m
Apr. 1	κ Tauri	6	8 28	13	8 48	338	0 20
4	ω^2 Cancri	6	9 46	99	10 56	301	1 10
7	*i* Leonis	6	7 51	164	8 56	260	1 05
10	γ^1 Virginis	3	6 54	202	7 05	220	0 11
10	38 Virginis	6	16 08	173	16 48	247	0 40
12	Uranus		11 48	126	13 14	311	1 26
15	25 Scorpii	6½	16 16	111	17 43	273	1 27
29	125 Tauri	6	9 42	114	10 28	248	0 46

Minima of Variable Stars of the Algol Type.

U CEPHEI.

R. A.....$0^h\ 52^m\ 32^s$
Decl.....$+ 81°\ 17'$
Period.....$2d\ 11^h\ 50^m$

Apr.		
1	8	P. M.
6	8	"
11	7	"
16	7	"
21	7	"
26	6	"

S ANTLIÆ.

R. A.....$9^h\ 27^m\ 30^s$
Decl.....$- 28°\ 09'$
Period.....$0d\ 07^h\ 47^m$

Apr.		
1	8	P. M.
2	8	"
3	7	"
10	10	"
11	9	"
12	9	"
13	8	"
14	7	"
15	7	"
21	10	"
22	9	"
23	9	"
24	8	"
25	7	P. M.
26	7	"

δ LIBRÆ.

R. A.....$14^h\ 55^m\ 06^s$
Decl.....$- 8°\ 05'$
Period.....$2d\ 07^h\ 51^m$

Apr.		
1	midn.	
8	"	
15	"	
23	11	P. M.
29	11	"

U CORONÆ.

R. A.....$15^h\ 13^m\ 43^s$
Decl.....$+ 32°\ 03'$
Period.....$3d\ 10^h\ 51^m$

Apr.		
9	4	A. M.
16	2	"
22	midn.	
29	9	P. M.

U OPHIUCHI.

R. A.....$17^h\ 10^m\ 56^s$
Decl.....$+ 1°\ 20'$
Period.....$0d\ 20^h\ 08^m$

Apr.		
4	2	A. M.
4	11	P. M.
9	3	A. M.
9	11	P. M.
14	4	A. M.

U OPHIUCHI CONT.

Apr.		
14	midn.	
19	5	A. M.
20	1	"
24	6	"
25	2	"
25	10	P. M.
29	7	A. M.
30	3	P. M.
30	11	"

Y CYGNI.

R. A.....$20^h\ 47^m\ 40^s$
Decl.....$+ 34°\ 15'$
Period.....$1d\ 11^h\ 56^m$

Apr.		
3	6	A. M.
6	6	"
9	6	"
12	6	"
15	6	"
18	6	"
21	6	"
24	5	"
27	5	"
30	5	"

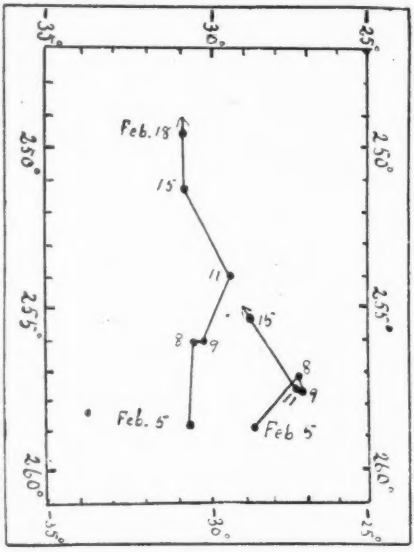
A Total Eclipse of the Sun April 26.—This will be visible as a total eclipse only in the South Pacific Ocean. Partial phase visible on the western coast of South America. The conditions of the eclipse render it of practically no scientific interest.

Two New Nebulæ. While looking for Winnecke's comet on Feb. 24 and 24 I came across two nebulæ which are not given in Dreyer's New General Catalogue. Both are very faint and can only be seen with large telescopes. Their approximate positions are:

	R. A.	Decl.
1	$13^h\ 03^m\ 20^s$	$+ 21°\ 37'.6$
2	12 54	+ 22 26

In the same vicinity is the bright nebula M 64 = N. G. C. 4826, which the beginner in comet-seeking must not mistake for a comet. H. C. W.

A Great Sunspot. On Feb. 4, one of the largest sunspots which has been seen for many years, appeared on the east limb of the Sun. A few days later it was easily seen without the aid of a telescope, by protecting the eye with colored glass. Measures of a photograph taken Feb. 11 when the spot was nearest the center of the Sun's disk give for the dimensions of the large single penumbra 72,000 by 33,000 miles, while the total disturbed area was 135,000 miles long and 80,000 miles wide.



The Sun was photographed at Goodsell Observatory on the dates Feb. 5, 8, 9, 11, 15, 16 and 18, by Mr. A. G. Sivaslian, a student in advanced astronomy and mathematics, who has charge of the work of taking daily photographs of the Sun. On the first of the above dates, the spot was quite near the east limb of the Sun and on the last date part of the spot was actually on the west limb. From measures of these photographs we have calculated the latitude and longitude of the two principal black centers of the spot on the several dates. These are platted in the diagram, and indicate considerable motion in both centers, both moving backward in longitude, the one about twice as fast as the other.

	Central Time.	A.		B.	
	h m	Longitude. °	Latitude. °	Longitude. °	Latitude. °
Feb. 5	12 16	258.7	— 28.7	258.8	— 30.7
8	4 12	257.1	— 27.2	256.0	— 30.5
9	12 36	257.7	— 27.1	256.0	— 30.2
11	12 37	257.5	— 27.2	254.0	— 29.4
15	12 33	255.4	— 28.8	251.2	— 30.9
16	12 48	255.4	— 29.4	250.4	— 31.0
18	12 24			249.6	— 30.9

The photograph of Feb. 16 was overlooked when the diagram was made.

Relative to a point half way between them the spots in ten days revolved through an angle of about 75° in the direction of the motion of the hands of a clock. It is evident from an inspection of the series of photographs that the large penumbra revolved with the two umbræ, but that the small outlying spots did not share in the rotary movement.

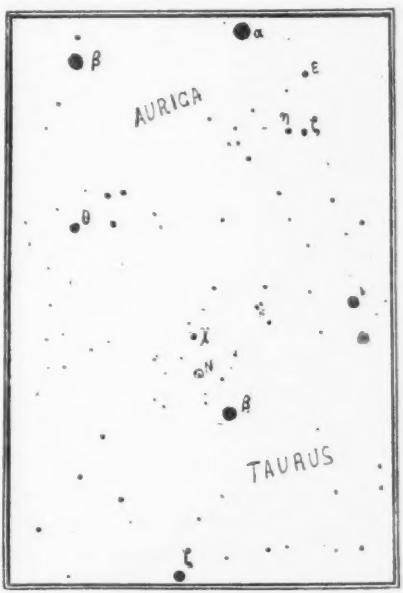
In the spectrum of the spot the C line was plainly reversed in many portions of the spot. In the north following portions of the two principal umbræ, on Feb. 15, the C line was very brilliantly reversed. In the D and F lines also the reversal was easily noticed. On Feb. 16 a photograph was taken of the H and K regions of the spot spectrum of the fourth order. This photograph shows H and K with a fine reversed line in each extending across the whole width of the spot spectrum.

In looking over our photographs during January I find that the birth of this group of spots occurred between Jan. 15 and 18. On the 15th there was a single round spot in longitude 276°, latitude − 24°, with no others in the vicinity. On the 18th, a new group of very prominent spots was photographed just east of this spot. The movement of the new spots is well shown by the following measures:

		a.		*b.*	
	h m	Longitude. °	Latitude. °	Longitude. °	Latitude. °
Jan. 18	12 05	268.1	− 24.9	260.6	− 26.5
19	12 06	267.4	− 26.0	259.9	− 27.6
20	12 56	265.9	− 26.4	258.2	− 27.9

We may expect the spot to appear again on the east limb of the Sun about March 1. H. C. W.

The New Star in Auriga. The most noticeable astronomical event of the past month was the discovery of a new star of the fifth magnitude in the constellation Auriga. This discovery appears to have been made by one who was not a professional astronomer, and who was unwilling to give his name. For a description of the new star and its spectrum we refer the reader to the articles by Messrs. Pickering, Crew and Hale, pp. 233, 228, and 231. The accompanying diagram, showing the position of the new star with reference to the principal stars of Auriga and the horns of Taurus, will enable the amateur to readily identify the star with an opera glass. It is about 2° northeast of the second magnitude star, β Tauri, at the point marked N in the diagram.



This region of the sky was photographed at Goodsell Observatory, Feb. 25, with a camera and Darlot projecting lens of 2½-inches aperture. The exposure was one hour with a Seed plate No. 26. On this plate the new star is almost exactly equal to χ Aurigæ and brighter than 26 Aurigæ.

The Aurora of Feb. 13, 1892.—This was noticed at Northfield at 6:20 P. M., and lasted until 7:20. The dark arch was about 40° high. The bright arch extended to 60° and at times to 85° altitude. The color of the auroral light was a beautiful pink during most of the time. At first there were streamers converging toward the zenith but these soon disappeared.

Mr. W. E. Woods, of Washington, D. C., reports spectroscopic observations of the aurora. He found four bright bands on a faint contintous spectrum. The

most brilliant was in the red about where C should be, and could be seen with a very narrow slit. The second was in the beginning of the green and was strong with a narrow slit. The third was in the blue and the fourth, very faint, in the violet. H. C. W.

COMET NOTES.

Tempel's First Periodic Comet (1867 II). In *Astr. Nach.*, No. 3075, Mr. R. Gautier gives a search-ephemeris for Tempel's first periodic comet, which is due at perihelion about the first of April. We give below those parts of the ephemerides which apply to the months of March and April. This comet has been observed at three apparitions, 1867, 1873 and 1879, but escaped detection in 1885, because of its very unfavorable position. The time of its perihelion passage is somewhat uncertain, because of the effect of perturbations by Jupiter in 1881 and 1882, which according to Gautier increased the period from 5.98 to 6.51 years. In calculating his ephemerides Mr. Gautier has taken account of the perturbations by Jupiter from 1885 to 1892, obtaining thus corrections to the elements adopted by him for the apparition of 1885. The elements for 1892 are:

$$\left.\begin{array}{lll} T & = 1892 \text{ April } 3.5 \text{ Berlin M. T.} & \\ \omega & = 168^\circ\ 58'\ 10.8'' & \\ \Omega & = 72\ 33\ 42.2 & 1892.0 \\ i & = 10\ 50\ 27.8 & \\ \varphi & = 23\ 53\ 57.0 & \\ \mu & = 545.0'' & \end{array}\right\}$$

Because of the uncertainty of the time of perihelion passage Mr. Gautier has computedthree ephemerides, adopting as the dates of perihelion March 24.5, April 3.5 and April 13.5, and giving the preference to the middle date.

The position of the comet is a little more favorable than in 1885. It must be looked for in the morning in the south-eastern part of Ophiuchus, and north-western part of Sagittarius. This region is a part of the Milky Way, and the nebulous back-ground of the sky will doubtless make it difficult to find the comet.

Search Ephemeris for Comet 1867 II (Tempel's Periodic Comet.)

Perihelion = April 3.5.

1892.	R. A.	Decl.	log *r*.	log Δ
	h m	° ′		
March 11	17 24.1	− 18 58.3	0.3184	0.2605
16	17 32.2	19 21.5		
21	17 39.9	19 44.4	0.3173	0.2333
26	17 47.2	20 07.1		
31	17 54.0	20 30.0	0.3169	0.2055
April 5	18 00.3	20 53.6		
10	18 06.1	21 18.1	0.3170	0.1773
15	18 11.2	21 43.9		
20	18 15.6	22 11.3	0.3177	0.1194
25	18 19.6	22 40.7		
30	18 22.4	− 23 12.3	0.3189	0.1227

	Perihelion = March 24.5.		Perihelion = April 13.5	
	R. A.	Decl.	R. A.	Decl.
	h m	° ′	h m	° ′
March 11	17 40.1	− 20 04	17 07.6	− 17 43
21	17 57.0	20 47	17 22.2	18 30
31	18 12.3	21 29	17 35.0	19 18
April 10	18 25.6	22 14	17 45.5	20 08
20	18 36.8	23 03	17 53.4	21 03
30	18 45.2	− 24 00	17 58.2	− 22 06

Brorsen's Short Period Comet. Mr. George A. Hill, in the last issue of your periodical (January 1892), gives some remarks on Brorsen's comet which require an answer.

Mr. Hill is "positive" that some errors have inserted themselves into Professor Schulze's calculation in *Astr. Nachr.*, vol. 93, page 177. But I found, as early as 1879 (*Astr. Nachr.*, vol. 95, page 45), that a slight variation of the perihelion time brought Schulze's elements very near to the observed path of Brorsen's comet in 1879. Dr. Wittstein in trying the same (*Astr. Nachr.*, vol. 94, page 351), was not even as much successful. Indeed, his ephemeris required, after some weeks, as great corrections as Professor Schulze's former calculation. You may judge from the following table of deviations (Obs.—Calc.):

1879	Schulze.		Wittstein.		Lamp.	
	$\Delta\alpha$	$\Delta\delta$	$\Delta\alpha$	$\Delta\delta$	$\Delta\alpha$	$\Delta\delta$
	s	′	s	′	s	′
April 20	− 1	− 39	+ 54	− 17	+ 1	0
25	− 28	− 42	+ 42	− 25	+ 1	0
30	− 89	− 44	− 5	− 34	+ 1	− 1
May 5	− 199	− 41	− 114	− 41	+ 1	− 1
10	− 329	− 32	− 302	− 39	− 1	− 1
15	− 395	− 19	− 462	− 28	− 3	− 1
20	− 370	− 6	− 501	− 13	− 6	− 1

Moreover, Dr. Wittstein's calculation, which is based on two observations, 1879, March 19th, and March 26th, (only seven days apart from each other), brings the comet in 1873, *toto cœlo* apart from the observed places, whereas Schulze and Lamp are in conformity to them. Nor was it Dr. Wittstein's purpose to give anyhow definitive elements.

May I ask Mr. George A. Hill to forward the publication of the results of his own work?

E. LAMP.

KIEL, STERNWARTE, 1892, Feb. 2.

Search Ephemeris for Comet Brooks, 1886 IV.

[From Astr. Nach. 3064, continued from page 169.]

	Perihelion, March 1.					Perihelion, March 31.				
	R. A.		Decl.		Light.	R. A.		Decl.		Light.
	h	m	°	′		h	m	°	′	
April 10	20	36.9	− 25	27	0.19	19	13.9	− 24	09	0.51
20	21	06.5	− 25	28	0.19	19	46.5	− 26	06	0.53
30	21	33.2	− 25	25	0.18	20	16.3	− 27	55	0.53
	Perihelion, April 30.					Perihelion, May 30.				
April 10	16	30.4	− 9	20	1.82	12	24.0	+ 24	06	1.11
20	16	50.0	− 14	30	2.11	12	17.6	+ 21	10	1.28
30	17	07.0	− 20	47	2.31	12	15.1	+ 16	55	1.42
	Perihelion, June 29.					Perihelion, July 29.				
April 10	10	03.8	+ 33	49	0.31					
20	10	06.2	+ 31	11	0.32	9	00.4	+ 34	28	0.12
30	10	13.2	+ 28	06	0.34	9	12.0	+ 31	39	0.12

Ephemeris of Comet *e* 1891 (Barnard Oct. 2.) As the light of this comet is diminishing rather slowly and the comet will be well up in northern latitudes in March, I have computed an ephemeris from Campbell's co-ordinates in hopes it may be recovered and receive observation.

G. M. T.	App. R. A.	App. Dec.	Log. r.	Log. Δ	Br.
	h m s	° ′			
Feb. 29.5	16 22 18	− 22 2	0.2983	0.2211	0.12
Mar. 1.5	21 53	21 36			
2.5	21 25	21 10			
3.5	20 54	20 44			
4.5	20 22	20 18	0.3089	0.2155	0.12
5.5	19 46	19 51			
6.5	19 8	19 24			
7.5	18 29	18 57			
8.5	17 47	18 30	0.3193	0.2103	0.12
9.5	17 3	18 2			
10.5	16 17	17 34			
11.5	15 28	17 6			
12.5	14 37	16 37	0.3294	0.2055	0.11
13.5	13 44	16 9			
14.5	12 48	15 40			
15.5	11 50	15 11			
16.5	10 50	14 41	0.3392	0.2014	0.11
17.5	9 47	14 12			
18.5	8 42	13 42			
19.5	7 35	13 12			
20.5	6 26	12 42	0.3488	0.1982	0.11
21.5	5 15	12 12			
22.5	4 3	11 41			
23.5	2 48	11 10			
24.5	1 32	10 40	0.3582	0.1961	0.10
25.5	16 0 14	10 9			
26.5	15 58 54	9 38			
27.5	57 32	9 7			
28.5	56 8	8 36	0.3674	0.1952	0.10
29.5	54 42	8 5			
30.5	53 14	7 34			
31.5	15 51 44	− 7 2			

O. C. WENDELL.

HARVARD COLLEGE OBSERVATORY, Feb. 13, 1892.

NEWS AND NOTES.

This number is a few days late because we waited for information concerning the new star in Auriga, and for tardy proofs.

In the February number of *The Observatory* is found a biographical sketch of Sir George Biddell Airy, accompanied by a beautiful photograph which was taken on his 90th birthday. It is fittingly made the frontispiece.

Remounting the 26-inch Equatorial at Naval Observatory. Messrs. Warner & Swasey, Cleveland, Ohio, have been awarded, by government officers, the contract for re-mounting the 26-inch equatorial, preparatory to its transfer from the old to the new Naval Observatory.

An Improvised Chronograph. Being desirous of making some record of occultations during the total eclipse of the Moon Nov. 15, I used the following arrangement for a chronograph. A good spring telegraph register was put in circuit with a clock and with a key at the observing telescope. To avoid the friction of a spring contact a very light strip of platinum foil was attached to the

lower part of the pendulum bob, and was made to swing through two drops of mercury which formed the terminals of the battery circuit. A second's mark was thus made on the paper about two millimeters long. The paper moved nearly four centimeters per second. An extra second hand on the axis of the escape wheel of the clock caused the tilting of a light lever once in a minute, which made another mercury contact, and this made a minute mark on the paper about 8 mm. long which was easily distinguished from the second's mark. An attendant marked with a pencil every five minutes the hour and minute opposite the minute mark.

The record of observation being made in 6 Morse letters there was no chance for ambiguity in interpreting the record except a short mark should have occurred *in* a minute mark. Even coincidence of a dot with a second's mark would hardly ever be so perfect that it could not be separated by careful spacing and measurement. The motion of the register was found to be quite uniform, so that a few measurements before and after a record would scarcely show any variation and the length would serve to decipher a record and fix the instant within one-fortieth of a second.

Given the exact local time, and a good clock and the personal equation, and very good work might be done with such apparatus. S. H. BRACKETT.

The Proper Motions of Stars. I recently examined the catalogue of the proper motions of the stars used by Mr. Dunkin in his computation of the position of the apex of the Sun's way (Mr. Main I believe is responsible for the catalogue) in connection with the *Draper Catalogue* of Stellar Spectra. Of the stars which I was able to identify and whose proper motion exceeded 0.2″ annually, 113 were referred in the *Draper Catalogue* to class 2 (solar stars) and only 32 to class 1 (Sirians). This result confirms generally the conclusions which I mentioned in your columns. But while a difference of 1.79 in magnitude would imply that a solar star was on the average about 2¼ times as far off as a Sirian of equal magnitude, I do not think the proper motions establish so high a ratio. Many explanations might be given of this circumstance. The solar stars may on the average have a larger mass (as seems to be the opinion of Mr. Maunder); or they may, on the average, move more slowly; or finally, there may be such an absorption of light in transmission as prevents a Sirian star from appearing as bright as a similar solar star when actually removed to 2¼ times the distance. Possibly all these causes may combine. I tried this in the case of the stars of the second magnitude (1.5 to 2.5 according to the *Harvard Photometry*) in consequence of the comparative slowness of their motions. I found as I expected that a majority were Sirians—20 Sirians to 15 Solars, more than one of the latter being marked with a query—but I further noticed that most of the Solar stars of this magnitude had a very slow motion and that their average proper motion did not exceed that of their Sirian compeers by more than 25 to 30 per cent. This proportion no doubt increases as we proceed and a faint Sirian star with large proper motion is almost unknown. Perhaps the broad distinction between Solar and Sirian stars is insufficient and that we must enter into the minute distinctions drawn in the *Draper Catalogue*. Indeed there are some startling differences in the photographic power of certain stars which even that catalogue refers to the same type. Thus β Cassiopeiæ is of magnitude 2.42 photometrically but only 3.63 photographically, whereas I find almost immediately after it a star in Pegasus (No 20 in the *Harvard Photometry*) referred to the same type (H) where the photographic magnitude is 6.58 and the photometric 6.63. And while the

average brilliancy of the Sirian binary stars is much above that of the Solar binaries, γ Leonis which has a Solar Spectrum figures at the head of the list.

An interesting question is the position of the stars with spectra of the third type as regards brilliancy. As far as I am at present able to judge, they are more likely to rank above than below the Solar stars. One of Mr. Gore's double stars, 36 Andromedae, is referred, but doubtfully, to this type in the *Draper Catalogue*. Its relative brightness is 6.23 which is above the average for the Solar stars but below that of the Sirians. The same doubt exists as to π Cephei, relative brightness 11.07, though in that case the second type gets the benefit of the doubt. The average for the Sirians is over 12.0. The proper motions of stars of the third type, as far as I have examined, average more than those of the Sirians of equal magnitude but never attain the high figures which occur with some of the Solars. The evidence of their intermediate position is indeed by no means conclusive, but it is suggestive of further inquiry. One thing that recent researches on this subject has, I think, rendered evident is that the promiscuous classing together of stars of nearly equal magnitude in such investigations as that relating to the Sun's motion in space is wholly inadmissible. The spectrum is an element of almost equal importance. W. H. S. MONCK.

DUBLIN, Jan. 9, 1892.

Manning M. Knapp was born in Bergen county, N. J., in 1823, and he was graduated from Rutgers College. He was admitted to the bar in 1846 and four years later was commissioned a Counsellor. He rapidly acquired fame as a learned lawyer and his knowledge of criminal law was so extensive that he was, in all important capital cases, assigned by the court to assist in the prosecution. When Judge Bedle was elected governor, he appointed the lawyer his successor on the bench in 1875.

Judge Knapp was re-appointed by Governor Ludlow, in 1882, and was, for a third time, appointed in 1889 by Governor Crew. On January 25th, he celebrated the seventeenth anniversary of his appointment as a supreme court judge. He expired suddenly, January 26th, while delivering a charge to the grand jury of Hudson county.

The dead man was a Democrat in politics but he was never a politician and never sought or held any elective office. He was one of the most expert judges of lenses for astronomical instruments in the country. Early in life he developed a love for the study of astronomy, but so frequently found lenses that did not suit him that he made them for his own use.

"At his home in Hackensack is a most complete workshop for the manufacture of lenses. He never sold any but frequently presented them to scientific societies. He was for years a close correspondent of Alvan Clark & Sons, the celebrated telescope lens makers, and his judgment of the quality of a lens was considered almost invaluable."—*N. Y. Tribune*, Jan. 27.

A Personal Explanation. It has occurred to me that some of your readers may possibly come across a copy of the morning's San Francisco *Examiner*, February 28, containing an article over my signature on *Astronomical Photography*, and in this event it would certainly seem strange to find that many ideas, and even certain paragraphs, are borrowed from a well known lecture by Professor Barnard of the Lick Observatory, entirely without credit. By one of those curious accidents which will sometimes happen, even in so admirably managed a daily newspaper, a line containing the proper acknowledgement was omitted, even after an insertion in the revised proof.

Of course Professor Barnard stands in need of no credit, for his work is familiar enough, even to those whose acquaintance with astronomical subjects is derived from the casual newspaper article. Therefore the present explanation is principally intended to avoid adverse criticism of the writer, should it happen that a popular article, written by a layman for the public press, fall into the hands of those qualified to detect such plagiarism. CHAS. B. HILL.

San Francisco, Cal.

Queries for Brief Answers. The following queries have been sent in by one of our subscribers. As some of them are of general interest to amateur astronomers we print them with the request that any who feel competent will send us brief answers. We cannot promise to publish all replies that may be given, but will try to select the best:

1. Has Foucault's pendulum experiment to prove the rotation of the earth on its axis ever been tried at, or near the equator, or in south latitude; and if so with what result?

2. Has the experiment of falling bodies, to prove the rotation of the earth on its axis, by deviation from a vertical line, ever been tried at the equator or in south latitude; and if so with what results?

3. How far ahead have eclipses been predicted, and where can I obtain a list?

4. Has it been proven or do astronomers generally believe that the planet Mercury rotates on his axis in the same time that he completes a revolution around the Sun?

5. In Chambers' Astronomy explaining the occurrence of a high tide on that side of the earth opposite to the Moon, it says: "It is only necessary to bear in mind that not only does the Moon attract the upper mass of water, but also the solid globe itself, which is consequently compelled to recede from the waters beneath, leaving them behind, and in a sense heaped together." This, or words to the same effect, is the explanation usually given in text-books on Astronomy and Physical Geography. Can that be explained to pupils in a simple way so that they, at least, will not be skeptical about it?

6. Who was it that said, "The undevout astronomer is mad?" G. I. H.

Government Astronomer H. C. Russell at Sydney, Australia, has favored Good sell Observatory with a number of valuable papers on Astronomical themes as follows:

On the Nebula and Stars about η Argus, March 1871.
The Colored Stars about Kappa Crucis, May, 1872.
Double Stars Results, 1871—1881.
Some Double Stars and Southern Binaries, June 2, 1880.
Recent Changes in the Surface of Jupiter, December 1, 1880.
Transit of Mercury, Nov. 8, 1881, December 7, 1881.
New Double Stars September 5, 1883.
On the Increasing Magnitude of Eta Argus, June 6, 1888.
On Some Celestial Photographs Recently taken at Sydney Observatory, November, 1890.
On an Electrical Control for Driving Clocks, November, 1890.
On Some Photographs of the Milky Way, Recently Taken at Sydney Observatory, Aug. 1890.
Results of Double Star Measures, 1891.
Preparations Now Being Made in Sydney Observatory for the Photographic Chart of the Heavens, July 1, 1891.
Notes on Some Celestial Photographs Recently Taken at the Sydney Observatory, Sept. 26, 1891.

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Camden Astronomical Society. At the regular meetings the Camden Astronomical Society held during last year, the following papers were read—

The Astronomy of the Ancients—Rev. Chas. Bowden.
The Manufacture of Astronomical instruments—A. B. Depuy.
Greenwich Observatory—H. H. Furness, Jr.
Personal Equation in Double Star Observation—Professor F. P. Leavenworth.
The Law of the Sun's Rotation and the Periodicity of Sun Spots—a translation from the German of Dr. F. Wilsing—Professor E. S. Crawley.

Mr. A. B. Depuy having moved from the city he tendered his resignation as secretary and Mr. H. H. Furness, Jr., was elected to fill the vacancy. R.

Meeting of the Astronomical Society of the Pacific, Jan. 30, 1892. The first meeting of the year was held in the lecture hall of the California Academy of Sciences, and was very largely attended. At the meeting of the directors held in the Society's rooms immediately before the regular meeting thirty-eight candidates were duly elected to membership, as follows:

A. B. Alexander, Richard H. Allen, W. S. Andrews, F. R. Bissell, Miss Mary E. Byrd, Miss Caroline A. Clark, Charles A. Crackbon, Frank H. Dickey, Charles R. Eastman, Geo. Stuart Forbes, Charles Graves, T. P. Gray, Alva J. Grover, Stephen M. Hadley, H. S. Herrick, John B. Lewis, J. A. Lighthipe, Marsden Manson, David Miller, James Moore, Chas. Nordhoff, Miss Clara A. Pease, Thomas Porter, M. Reimans, George A. Ross, John R. Ruckstell, Roger Sprague, Miss Henrietta Strong, Mrs. Wm. Emerson Strong, C. L. Taylor, Senor Enrique Toriella, Professor L. W. Underwood, Professor L. G. Weld, James A. Wilson, Wm. C. Bonsfield, Adolph Lietz, Professor Wm. Lymmons, Joseph C. Sala.

At the regular meeting President Pierson presided. The thanks of the Society were voted to the California Academy of Sciences for the free use of the auditorium. A number of presents were announced by the secretary, who called attention to the beautiful colored lithograph of the partially eclipsed moon of November, 1888, drawn by Professor, Weinek, of Prague, who had presented the society with 1,000 copies for the Publications of the Society.

The following papers were presented:

a. The Rotation of the Sun (translation from the German of Dr. Schmidt) by A. C. Behr, of Chicago.
b. Pogson's Comet and the Bielan Meteors, by W. H. S. Monck, of Dublin, Ireland.
c. The McKim Observatory, by Professor W. V. Brown, of Greencastle, Ind.
d. When shall we have Another Glacial Epoch? by Garrett P. Serviss of New York City.
e. The total Eclipse of the Moon, January 28, 1888, by Professor Weinek, of Prague (translated by F. R. Ziel, San Francisco).
f. Lantern Slide Exhibition, Lecture by W. W. Campbell of the Lick Observatory.

The President appointed the following committees to report at the annual meeting March 26th.

A committee to nominate Directors and publication committee: Messrs. José Costa, F. H. McConnell, Hon. Arthur Rogers, Harry Durbrow and Edward R. Young.

A committee to audit the accounts of the treasurer: Messrs. M. M. O'Shaughnessy, Otto Von Geldern and F. W. Zeile. The hall was then darkened and seventy-five lantern slides exhibited by Professor Campbell illustrating the methods and results of the Lick and other Observatories.

The president announced that a branch of the society was being organized in Pittsburg similar to the Chicago branch.

The meeting then adjourned.

CHARLES BURCKHALTER, Secretary.

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